European Commission

Proceedings of the 7th International Conference on Energy Efficiency in Commercial Buildings IEECB'12

Paolo Bertoldi
Gueorgui Trenev

JOINT RESEARCH CENTRE

2013

Report EUR 25759 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Energy and Transport

Contact information
Paolo Bertoldi
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 450, 21027 Ispra (VA), Italy
E-mail: paolo.bertoldi@ec.europa.eu
Tel.: +39 0332 78 9299
Fax: +39 0332 78 9992
www.jrc.ec.europa.eu
http://re.jrc.ec.europa.eu/energyefficiency/

JRC 75412

EUR 25759 EN

ISBN 978-92-79-28222-5 (pdf)
ISBN 978-92-79-28223-2 (print)

ISSN 1831-9424 (online)
ISSN 1018-5593 (print)

doi: 10.2790/77021

Luxembourg: Publications Office of the European Union, 2013

Printed in Italy

Proceedings of the 7th International Conference on Energy Efficiency in Commercial Buildings IEECB 12

Paolo Bertoldi

Gueorgui Trenev

JOINT RESEARCH CENTRE

Contents

Policies and programmes

HVAC

Lighting

Examples

ESCO's

Energy monitoring and control

Behaviour

Planning and design

Barriers to achieving Energy and Carbon reductions in New-Built and Refurbished schools in England

Amrita Dasgupta[1, 2], Michael Roberts[1], Paul Cropper[1],

[1]Institute of Energy and Sustainable Development, De Montfort University, Leicester

[2]Leicester City Council

Abstract

School Buildings in UK account for a significant proportion of the carbon emissions from public buildings. Under the CRC Energy Efficiency Scheme in the UK, Local Authorities will be charged a carbon tax for their emissions [1]. The carbon tax coupled with energy bills severely constraint the educational budgets available to schools. The Building Schools for the Future (BSF) programme and Primary Capital Programme (PCP) were established to rebuild and refurbish school buildings throughout England and Wales. However post occupancy evaluations have shown that newly built schools are failing to meet even basic performance criteria relating to both energy consumption and indoor air quality, imposing a tremendous challenge to achieving carbon reductions.

To optimize the carbon and energy reductions in schools, every stage of the process from policy and planning to de-commissioning needs to be influenced and well integrated into a sustainable framework. Contractual requirements, procurement frameworks, commissioning and facility management all have a critical role to play to reduce emissions in operation of the building. However barriers within regulations, design methodologies and processes have limited the impact of carbon reductions. This paper identifies some of these barriers and further highlights their impact on the scope for carbon reduction.

Introduction

The United Kingdom (UK) has committed to reducing energy consumption by 80% against the 1990 baseline by 2050 [2]. This ambitious target is expected to be met by a balance of mixed measure, with priorities towards renewable energy and energy efficiency [3]. Nationally, schools alone are responsible for 15% of the total energy consumption in public and commercial buildings [4]. Locally, schools in England contribute to around 50% of a Local Authority's (LA) carbon emissions [5] and as such form a substantial part of the LA's carbon tax and energy payment. It is thus critical to address the issues of school's carbon emissions, not only to contribute to the 80% reduction target, but also to firmly embed the principles of Sustainable Development within the day to day activities of the school, exemplified by the UK Government's 8 Doorways Framework.

There are approximately 25,000 maintained schools in England and Wales with a total school area of 60,000,000 m^2 (645834625 ft^2) and a replacement value of £130 billion [6] In addition to a £1.5 billion annual spend on maintenance of school buildings, the annual spend on energy in year 2006-2007 exceeded £420 million. Further, the CRC Energy Efficiency scheme – a mandatory emissions trading scheme was launched in April 2010. The primary aim of the CRC is to promote energy efficiency and reduce carbon emissions from all large organizations in UK by charging a tax on every tone of carbon emitted. All 433 local authorities are obliged to participate in the scheme [7]. Within the CRC legislation, maintained schools in England are included within their Local Authority's stationary sources, where the compliance with the CRC obligations rests with the Local Authority.

UK schools house nearly ten million pupils who spend almost 30% of their life in schools and about 70% of their time inside a classroom on school days. The indoor environmental quality of the classroom not only affects the health and thermal comfort of pupils [8, 9] but can also impair learning performance and increase absenteeism [10, 11, and 12].

Post Occupancy Evaluation (POE)

Post-occupancy evaluation (POE) is a practice designed to review a building once it has been occupied. In the examples below, several POE studies examine energy performance and internal environment conditions in newly built schools.

A long-term strategy for reducing emissions involves replacing old and inefficient buildings with new low-carbon buildings, delivering equivalent or better levels of service. However three major studies focussing on operational performance of newly built 'low carbon schools' have shown that new schools are failing to meet even basic criteria related to both energy consumption [13, 14] and provision of indoor environmental quality (acoustics, indoor air quality, thermal comfort and lighting) [15].

The first study analyzed sources of discrepancy between predicted and actual energy performance in five 'low energy' UK schools. The carbon emission of four of the schools evaluated were greater than the median UK school building, and whilst the fifth showed only marginally better performance [13]. The UK Government energy benchmarks for the median UK school building are based on return data from schools (made up mainly of Victorian and 1950s buildings) are: 155 kWh/m^2 for fossil fuel consumption, 39kWh/m^2 for electricity consumption, and a total carbon emission of 53kgCO$_2$/m^2 [16]. Furthermore, the energy prediction analysis indicated between 57% and 66% error on total carbon emission based on measured data associated with the building.

To overcome the limitations of the case study approach, the second study – CarbonBuzz compares designed energy use with actual energy use of recently completed projects [14]. The dataset created enables researchers to more accurately quantify a significant gap between design stage estimates and actual energy performance of buildings, compare the actual energy use against CIBSE TM 46 Energy Benchmarks [17], and to better understand sources of unregulated energy consumption in buildings. Project data entered by practices is sourced from existing M&E documentation, Part L Report (a regulatory energy conservation compliance document of the Building Regulations used in England and Wales) and post occupancy evaluations. As of December 2010, based on available data for 43 school buildings, the actual energy use in a newly built school is approximately 2.4 times higher than the designed value, and on aggregate schools evaluated emitted approximately 20% more carbon emission than suggested by CIBSE TM 46.

A Carbon foot printing study was conducted by BISRIA on three primary schools – a Victorian school built over 100 years ago, a school built in 1970s and a new school designed to the latest building and energy efficiency standards recognized as an exemplar of sustainable design [18]. The study indicated that carbon emissions of the new built school are in line with the Victorian school; even though the Victorian building hasn't had any improvements and is characterized by single glazing and old gas boilers. The report concludes that replacing school buildings to modern building regulation standards may not automatically improve its carbon footprint. The study advocates that new energy efficient saving technologies are more complex and demanding to run and can put school administrators on a management and maintenance regime that they are neither experienced not trained to handle.

Methodology

POEs have shown that school building pose a tremendous challenge in terms of managing energy consumption and reducing Carbon Emissions. The complexity of school buildings due to their varying, occupancy, ICT requirements and hours of use form only some of the challenges to reducing Carbon Emissions. Furthermore POE has demonstrated that newly built schools in UK have much higher energy consumption and carbon emission than predicted at design stage. Such a trend proves to be a substantial financial as well as environmental risk. It is thus necessary to identify the critical challenges and barriers that influence achieving carbon reduction targets in schools.

This paper is based on the findings of a Knowledge Transfer Partnership (KTP) between Leicester City Council and De Montfort University. The KTP is currently engaging with Low Carbon School Design for the Local Authority while also trying to embed knowledge within the staff and their design advisors. The results of the study are based on practical experiences and lessons learnt during the involvement within the BSF and PCP projects in Leicester. The paper also uses the results of an online survey conducted with 300 members of the CIBSE School Design Group, of which 286 professionals responded. These members represent UK-based professionals who have been working and researching in the field of low carbon building design with a specific interest in the education sector.

Further research has begun to look at the more notional definition of what is to be a "sustainable school". This holistic approach has involved combining and refining existing models of sustainable development to improve the way the physical environment connects with the educational and social performance of a school.

Results: Barriers to reducing energy and carbon in schools

The ongoing research under the KTP has highlighted issues pertaining to policy, design, procurement and commissioning of schools that have a substantial effect on the overall energy consumption of the schools. The research attempts to identify and measure a range of social and technical factors which help to explain the post-occupancy performance of schools. This paper identifies some of the important lessons learnt in delivering low carbon schools and highlights some of the key barriers to achieving carbon reductions in schools.

1. Funding

School Buildings in UK had been built in two waves; the first being the Victorian schools built in 1870, while the second built around 1940 - 50s [19]. A majority of this stock of buildings have surpassed their life-cycle and experience substantial structural and environmental issues. With a view to addressing issues of environmental quality, safe learning spaces and energy use in building, the biggest school building programme since Victorian times was introduced in 2006. This included the £45 billion BSF which aimed to rebuild and refurbish the entire 3500 secondary school stock and the PCP which anticipated refurbishing 50% of the 18000 primary schools over a period of 15 years [20]. However, in 2010 the BSF programme was reduced to 600 schools with a further 60% cut announced on both the programmes under the comprehensive spending review [21]. To add to these, increasing demographic has led to the demand of additional school places for children. The demand for energy thus is expected to increase rather than decrease given the current trends. However with the introduction of the CRC Energy efficiency scheme, carbon reductions in the Capital Programmes still remain a high priority.

The last published Carbon Management Strategy for schools recommends that in order to meet the 80% UK carbon target, a 53% reduction in carbon emissions in the schools estate by 2020 will be needed [22]. Modeling prior to the government's spending review suggested that in the absence of higher carbon reduction interventions compared to those being implemented, the carbon emissions from English school estates would remain relatively constant through to 2050 [22]. However, the cuts through the 2010 Comprehensive Spending Review have restricted the scope of carbon reduction in the schools estate. With a lack of any substantial funding, the scope for building improvements has been severely limited in the schools that are still being refurbished and have completely stopped in the schools that lost the funding. Carbon emissions are further amplified by growing pupil numbers, increased ICT use and increased dependence on air-conditioning due to overheating.

The James Review [23], commissioned by the Secretary of State for Education, was written to examine the lessons learnt from the Building Schools for the Future programme, setting out a new plan of action for the future. Five core objectives were identified; Good value for money, helping to reduce the government's deficit; Raise standards; Tackle disadvantage; Address building condition; Meet the requirement for school places resulting from an increase in birth rate

In their analysis, BSF was "complex, time-consuming, expensive and opaque indicating potential savings of up to 30% through streamlined processes" and that a "lack of expertise" among those procuring the buildings meant there was little opportunity to lower costs or improve buildings methods. Designs were said to be "far too bespoke and there was no evidence of an effective way of learning lessons from mistakes and success. Moreover, the regulatory and planning environment was considered to be far too complex, consisting of 3,000+ pages of related guidelines just for schools.

Alarmingly however, energy efficiency was barely mentioned throughout the report, an oversight that appears to repeat the mistakes of the past. The challenge is therefore not only to improve the technical expertise of sustainable buildings, but to make aware and persuade policy makers that energy efficiency must become a core priority.

Low Carbon Design is a new and developing market, with limited information on success and benefits against rapidly fluctuating energy markets. Information about capital costs is emerging slowly and there is still uncertainty about life-cycle costing. People controlling the cost plans (including clients) are unaware of the benefits of life cycle costs of low carbon designs and tend to base their judgements on capital costs. This has been further substantiated by the survey (Ref fig 1,2). This trend is often amplified in Local Authorities who make the initial capital investment in the building but do not share the benefits of reduced energy costs with the schools. Low carbon design requires innovative approaches to design, but construction companies are often inhibited to take risks due to stringent contractual requirements and prefer to follow accepted solutions within the industry to avoid litigations and added financial costs.

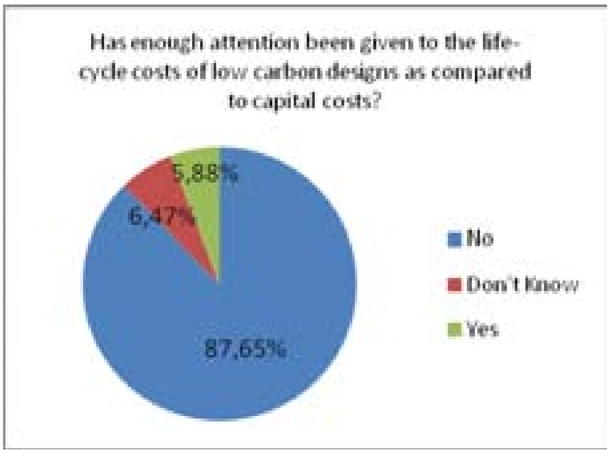


Figure 2: Survey results: Comparison of importance given to capital costs over whole-life cycle cost

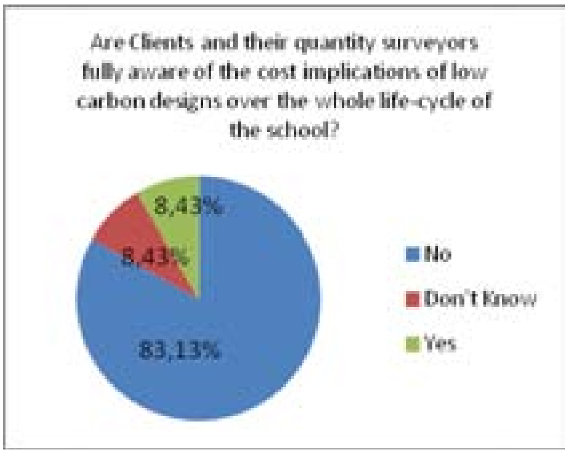


Figure 1: Survey results: Awareness on whole life cycle costs

2. Policy, Regulation, Guidelines and Tools

a. Use of energy compliance model for school predicted energy use:

Energy and Carbon reductions in school Capital project are driven by the Building Regulations (legal minimum standards required for all building work in the UK), which ensure flexibility in design, but require the design to demonstrate that a new building will perform better than a "notional" building of the same size, shape, and function [24].

The compliance process is defined by the “National Calculation Method” (NCM) for the EPBD (Energy Performance of Buildings Directive) which is defined by the Department for Communities and Local Government (DCLG). The procedure for demonstrating compliance with the Building Regulations for buildings other than dwellings is by calculating the annual energy use for a proposed building and comparing it with the energy use of a comparable ‘notional’ building. Both calculations make use of a standard set of data (referred to as the NCM templates) for different activity areas and call on common database of construction and service elements. The calculations are carried out either by approved simulation software or a simplified purpose built tool developed for DCLG by the Building Research Establishment (BRE). It is to be noted that the compliance methodology does not include non-regulated energy loads. Such a process can lead to a significant underestimation of the future building energy consumption if it is assumed that the compliance model predicts total energy consumption. Another potential source of error comes from the use of NCM templates which may not accurately reflect the actual building design. As a result significant increase in energy consumption is observed when the buildings become operational. The approach results in a cumulative miscalculation of predicted energy consumption across the entire school’s capital programme and thus significantly affects the carbon targets set forth by Local Authorities. This underestimation can be further amplified by the use of the school buildings outside core school hours, or by heating and lighting the buildings when unoccupied to meet contractual obligations. It is to be noted that the compliance energy model is purely a tool to understand the energy consumption of the new building as compared to the notional building and thus does not account for any consumption beyond core school hours.

Ideally the energy performance software should be used as a design tool incorporating actual design data and regulated and unregulated load to predict the energy consumption and building performance. This should be based on total hours rather than being restricted to core school hours. The benefits of such a process can be realised through multiple simulations within the design process to continuously evaluate the performance of the design against choices made. The final energy model thus must achieve higher energy reductions than those predicted purely through a compliance model.

In reality however contractual processes and financial limitations often lead to the model being run only twice during the design process – once at contractual close (RIBA Stage D) and second prior to handover of the building. On the first occasion much of the required information such as ICT loads may not be known. On the second occasion the design process may be too advanced for major changes to be incorporated.

The current school regulatory framework, a set of 30 Building Bulletins (BBs) ranging from ventilation and indoor air quality (BB101) to acoustics (BB93) and environmental design (BB87) set out parameters within which design develops, The nature and structure of environmental performance requirements (temperature, lighting levels etc.) is found to be of key importance since they effectively determine the viability of more vulnerable solutions such as natural ventilation. Building bulletins form a part of the construction contract. They can inhibit the process by providing absolute requirements. An example of this is the absolute figures proposed by Building Bulletin 101 to avoid overheating in schools [25]. Single figure summertime temperatures are not deliverable via the use of pure natural ventilation strategy cooling as this tends to deliver a temperature range relative to the outside temperature rather than an absolute temperature prescribed regardless of the weather. Further, natural ventilation solutions are unpredictable when they are required to deliver absolute temperatures. As a result there is an increased tendency to adopt mechanical and energy intensive solutions to meet the rigid criteria specified in building bulletins. The increased reliance on mechanically ventilated solutions is largely due to their predictable nature and ease of design. Design guidelines are often misinterpreted, imposing rigid constraints on designs often leading to carbon intensive solutions in order to avoid litigation (Ref Fig 3,4)

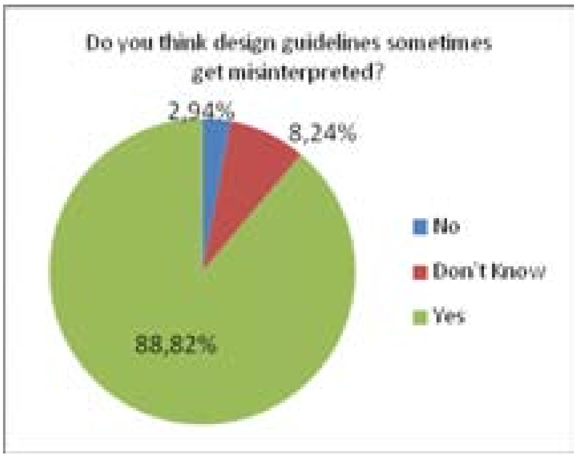


Figure 3: Survey Results: Misinterpretation of design guidelines

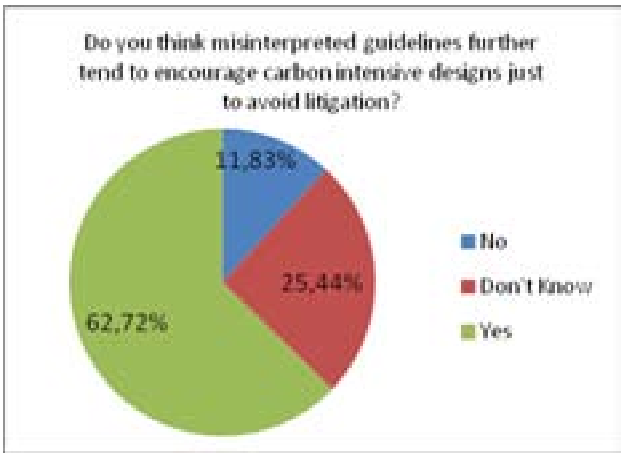


Figure 4: Survey Results: Misinterpreted guidelines further tend to encourage carbon intensive designs just to avoid litigation

3. Design

a. Overheating in schools:

A significant challenge facing schools is the growing frequency of overheating in buildings which results in the use of air-conditioning units. These could be largely attributed to the following:

- Increase in internal heat emissions: This is due to the increase in equipments in operational phase of the building, which occurs mostly due to non-regulated load equipments being either reported late or not reported at all through the design process. Information Communication Technology (ICT) forms a part of the non-regulated loads. A significant challenge facing school energy demand is the growing numbers of ICT in teaching areas. ICT solutions have evolved from being used in ICT suites alone to being spread over teaching zones in a pupil to device ratio of 1:3 and 1:1. Not only does this increase the energy consumption due to increased equipment numbers but also increases cooling demand due to a rise in heat emissions from equipments. Their exact numbers, locations and specifications are often known quite late in the design process. The mobile nature of laptop trolleys makes them difficult to model at design stage. As a result ventilation solutions are often unable to cope with the large increase in internal heat emissions. Natural ventilations systems are often unpredictable due to changes in climate. There is further a lack of adequate knowledge within the industry to design effective solutions within the constraints of budget and resources available.

- Short project delivery timelines, financial limitations and rigid procurement frameworks have increased reliance on easy to install light-weight constructions which do not employ the benefits otherwise offered by heavy thermal mass and other passive design measures.

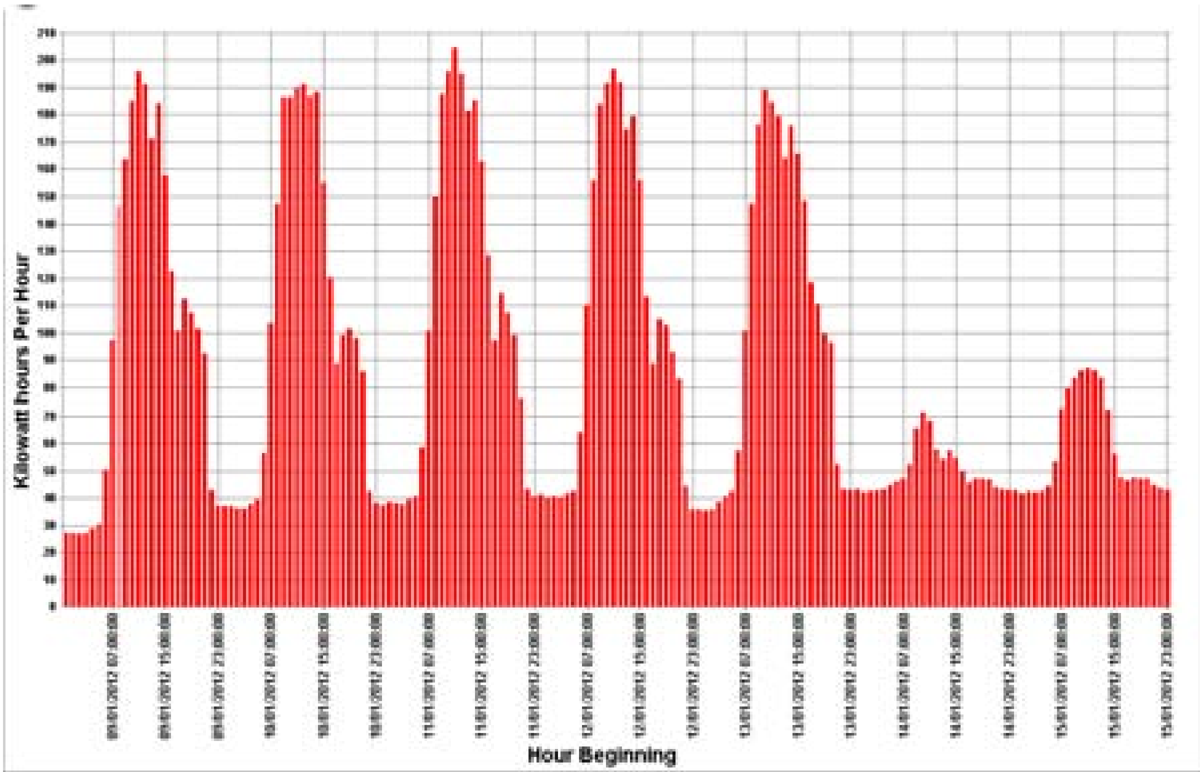
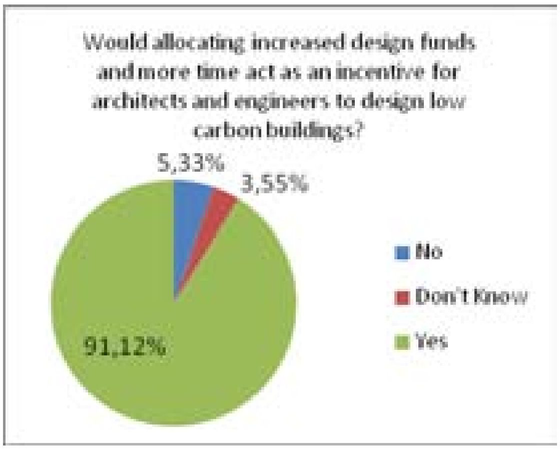


Figure 5: Electricity consumption in a Secondary School in Leicester showing community use and behavioural issues with energy use.

b. Role of predicting community use in actual energy consumption:

1.1 Schools buildings are often used beyond school hours for extended school periods and community use. The facilities are used to promote the development of the Local Community at subsidised commercial rates. This practice is greatly encouraged in Local Authorities, more so since the buildings themselves do not have a continuous year long use. Figure 5 shows the electricity consumption of a secondary school in Leicester indicating a high continued consumption after 3pm when the school shuts down but the facilities are continued to be used by the local community. The school is open from 8am to 10pm every week day and on Saturdays (8am to 4pm) and Sundays (6am to 2pm). This is a 365 day a year operation (except now for bank holidays and XMAS period recently).



During the design stage it is challenging to accurately predict the exact use of the building for such a function which is ever changing in nature. These zones if not designed sensitively are spread-out across the school leading to the entire building being lit, ventilated and heated in many instances during after hours. Contractual requirements push facility management companies to have the building available all through after hours even though they may be unoccupied or not used to their maximum capacity. Energy consumption in schools during after-hours is difficult to predict and substantially influence the difference between the predicted and actual energy consumption of the buildings. Appropriate zoning and controls in buildings are extremely beneficial to conserving energy. Some examples of this include:

a. Independent zoning of controls for north and south facing classrooms which have very different heating and lighting demands,
b. Combining all community used areas and allowing independent control for after-hour use.
c. Independent control of facilities based on function e.g. Sports Hall, Libraries, Labs

Figure 6: Survey Results: Increased design funds and time act as incentives for architects and engineers towards low carbon design of schools

However such design decisions most often need early engagement and are driven by the skill of the design team. They most often have added financial implications on the project itself. Low carbon designs presently do not have any increased design funds or design time allocated, to reflect the effort required to develop them.

c. Low/ Zero Carbon Technologies

The survey indicates that at present the current energy standards are not adequately equipped to drive low carbon technologies. In terms of energy generation, BREEAM provides credits to certain on-site technologies, many of which are highly inefficient and uneconomical at small scale, yet BREEAM does not allow credit for offsite technology which offers more economy to scale. Moreover, in particular energy resources such as wind and heat pumps, manufacturers' claim of performance are grossly exaggerated. The unreliability of the supply side of low carbon fuels leads to an apprehension towards the system as an aftermath. A large range of low and zero carbon technologies become unsuitable for schools due to their intermittent nature of annual demand. This section discusses some of these technologies.

BIO-MASS: Currently bio-mass boilers are considered to be economical, demand led and low carbon source for heating. Heating demands in classrooms are generally low. Pupils compensate for all fabric losses and major part of ventilation losses (BB-87). Equipment and solar gains further reduce heating demands. POE shows that heating in schools are characterized by spikes non-steady loads restricted to shorter periods (Refer Fig 7). .

In low energy schools, heating loads are expected to be almost near zero. Thus usually there is no expected base-load for heating. Bio-mass boilers have a slow response and need to run for longer periods to work effectively. They are thus unsuitable for spiky short-term loads unless demands are high due to large areas or facility (swimming pool) and there is a possibility of a thermal storage. In case of high heating demands it is uneconomical to design bio-mass boiler to address complete loads. It would ideally be supplemented with another system to meet peak conditions, resulting in a complicated and expensive solution with two systems. One of the biggest constraints in using bio-fuel based technology is the cost and storage requirements of the fuel and the reliability of the supply

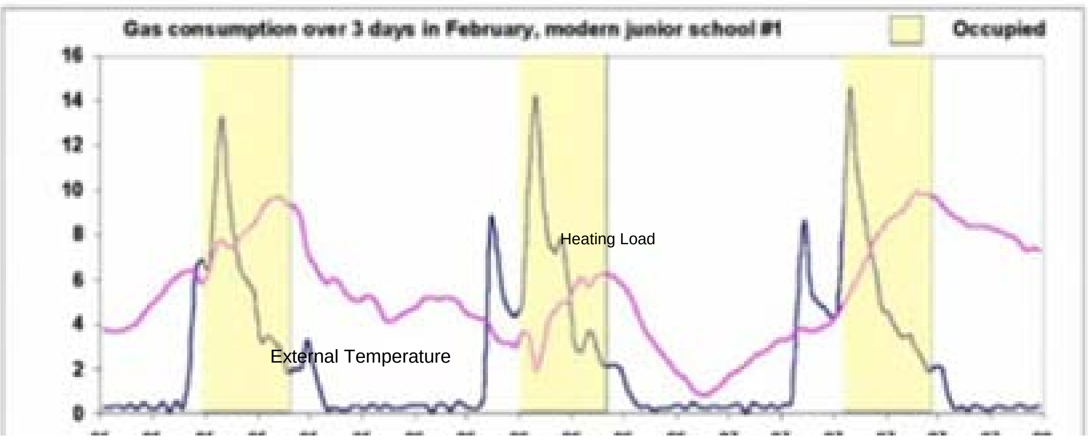


Figure 7: Spiky Heating Loads as indicated by Gas consumptions in a typical school

Source: Low Carbon Buildings Directory website, *Sharing Energy Supply and Low carbon Energy Supply*, CIBSE-SDG.

chain in delivering adequate quantity of fuel on time. In the POE conducted on four BSF schools in Leicester, it was seen that all four schools in operation were using secondary gas boilers as primary sources rather than the biomass boilers due to the excessive cost of the fuel.

Combined Heat and Power (CHP): CHPs are slow response systems and need to run at least 4000hrs/year to be viable. As in case of Bio-mass, CHP is not feasible for spiky short term heating demands of schools alone (Andrew Wright, CIBSE-SDG symposium, 2009). They are further uneconomical due to the lack of a year-round demand for energy. This could be successful though if the energy produced could be shared between schools and other buildings (e.g. residential) where heating demand profiles balance each other. This would be a very flexible solution for the future, where it is easy to shift between CHP and on-site heating systems as per needs. It reduces electricity cost, has a high efficiency (90%+) and low emissions, but it is not a viable option unless it is shared at a community level.

District Heating: District heating systems are comparatively simple and low cost. They have a fast response to start-up heating (beneficial for short-term loads) and are easy to handle at the use-end. It has a compact heat exchanger and no requirement for a boiler, thus it saves space. Depending upon the source of heat green-credits are awarded to these systems. However there may be distribution losses, but modern systems are found to prevent this as well. They are well suited to the demand profile for schools if the barriers corresponding to them could be overcome.

Ground Source Heat Pumps (GSHP): GSHP can provide cooling (without refrigerant if ground temperature is low enough) as well as heating. Their CO2 emissions are about 50% of gas (Mike Entwisle, CIBSE-SDG symposium, 2009) and its incentives include no visual impact, possibility of heat recovery, simple management post-installation and to an extent they are demand led (can address flexible occupancy hours). With GSHPs it is preferred to have balanced heating and cooling load in order to avoid changes in ground temperatures over time resulting in inefficiency of the system. There is an ongoing debate as to whether these should be used to meet large heating demands in schools due to their nature of low grade heat and extensive capital cost.

Solar Photo-Voltaic (PV) and Solar thermals: Solar radiations received in winter in UK are almost $1/4^{th}$ of the summers. UK also experiences a large number of overcast sky days.

<u>Solar Thermals:</u> During vacation periods almost 20% of total output is lost due to schools being closed. Energy is also lost during weekends, but most of the heat can be stored and used later.

<u>Solar PV:</u> PVs have a variable seasonal as well as daily load. It is not very economic to store, so it is best to either use it or export it. They have a high capital cost and maintenance cost (due to replacement of inverters). They can in most schools only generate 5% of the total electricity. They are believed to be excellent educational tools, but energy display boards have also found to use more energy than the PVs can generate. incentives with these are that they attract grants and renewable energy certificates.

Wind Energy: There is a large scope of using wind energy to generate power in UK. Availability of wind as a resource is much more constant through the year as compared to solar energy for PV. They have higher output in winter and low seasonal variations, but high variations in terms of day hour and second (day and second data). They are very site dependent and not suited for urban areas where availability of wind is obstructed by development. Micro-wind turbines are not a viable option partly due to turbulence in wind caused by surrounding buildings (Carbon trust, 2009). Further these systems have most often found to have poor paybacks, and opposition from local inhabitants due to noise and poor visual appeal.

As a serious resource large turbines are viable but are conflicted due to planning constraints. Moreover, the energy generated would be intermittent, difficult to store and would need to be either used or exported. The best option at present both in terms of economics and efficiency is to have energy produced in off-site wind farms where they can be best captured and fed into a central grid. Off-site solutions are further not supported under BREEAM.

4. Building Performance in Operation

"In order to achieve the leadership target of overall 42% reduction, energy related emissions would have to be reduced by at least 55%" [22]. The current trends in reducing energy in school buildings mainly refer to preventing excessive consumption of energy. Some of the most significant increase

between predicted and actual energy consumption can be attributed to unregulated energy use [14]. Unregulated energy use can be attributed to the following issues:

a. Increase in equipments from that predicted at design stage. This includes ICT, small power equipments and catering equipments
b. Change in function of building and increase of operating hours due to out-off hours use or use during holiday periods.
c. Inefficiency of the Building Management system due to either poor understanding, behavior of facility mangers or inefficiency within the system itself.
d. Behaviour of the occupants

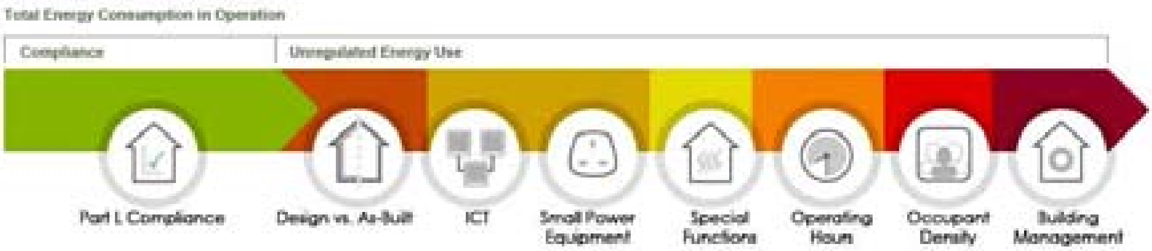


Figure 8: Total Energy Consumption in Operation Source: CarbonBuzz

a. Smart metering and Sub metering:

"A comprehensive programme of carbon standards, post occupancy evaluation, smart metering, behavioural change and refurbishment programmes could deliver a reduction in carbon emissions of between 53% and 59% by 2020."[22] To regulate increased energy consumption, employing energy management techniques including smart metering, proper facility management and creating awareness about behavioural impacts can substantially benefit the process. This has been further substantiated by the survey.

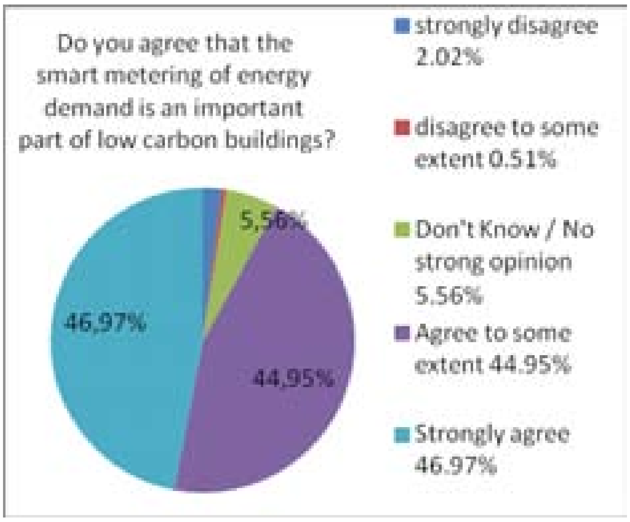


Figure 9: Survey Results: Smart Metering incentivise low carbon buildings

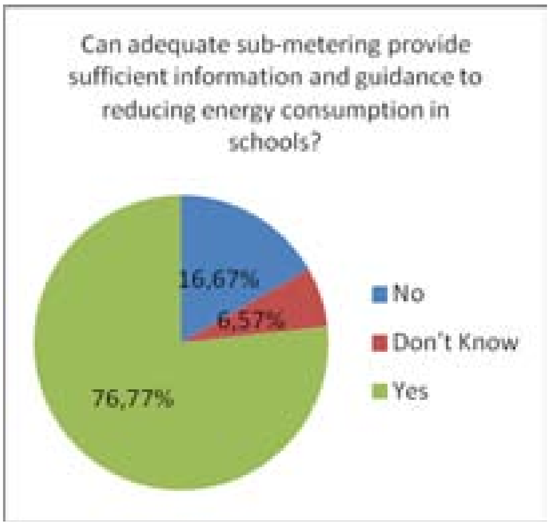


Figure 10: Survey Result: Sub Metering provides sufficient information to reduce energy consumption

Smart metering allows energy data to be collected at half hourly or even at real time rate. They support identification of leaks, faults within energy systems and behavioural issues of end users. The benefit of this however is voluntary in nature i.e. those who choose to maintain wasteful patterns may still do so. Smart Metering however when combined with policy, continuous monitoring, financial budgeting and involved in pedagogy has tremendous ability to affect behavioural pattern. Complimenting smart metering with sub metering can be used to further involve users in active programmes of energy reduction and also reduce time taken in identifying leaks and wastage. It is recommended that as a minimum heating, lighting, ICT, power, catering and water be segregated based on zones and building use and types.

b. Staff Training

Currently schools are either managed by facility management companies or as a combination through the school staff and the Local Authority. Local Authorities are most often tremendously under-resourced to manage the scale of the buildings estate owned, leaving the management of energy to the schools themselves. This is further emphasized due to schools having their devolved budgets and paying for their own energy bills. In schools unless the energy management is a key priority for the school, it is led by business managers/ bursars and the premises officer who most often have a non-technical background to manage energy. A continuous system of training and re-commissioning is needed to support non- technical staff in managing energy systems.

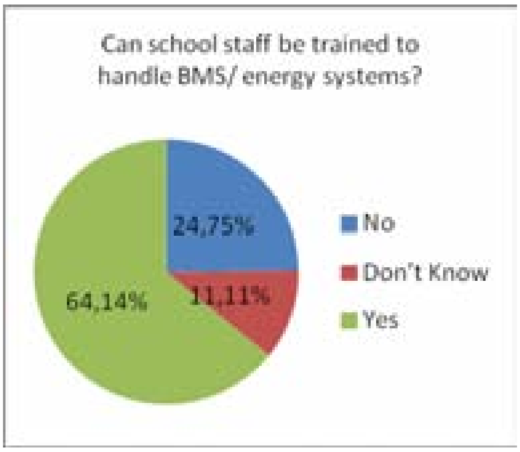


Figure 11: Survey Result: School staff can be trained to handle BMS/ Energy systems

The survey reflects the popular opinion amongst professionals that school staff can be trained to handle BMS systems. Educationists' are of the view that although teachers could be trained to handle BMS systems they most often do not want to be involved with them in addition to their schedule of works. POEs have shown that in many instances energy consumptions have increased in schools where the staff is allocated the job of operating energy systems. But these examples mostly refer to caretakers performing the job of facility managers.

Discussion

In order to meet the 80% UK carbon target, a 53% reduction in carbon emissions in the schools estate by 2020 will be needed. Research has already indicated that ongoing efforts to design Low Carbon Schools conducive to learning have had little success in UK. These are largely attributed to barriers within policy, regulations, design processes and solutions that lack a cohesive approach to low carbon design of school buildings. The current UK school building stock is representative of a large set of buildings that are beyond their current life cycle and experience substantial environmental and structural decay. There is a deficit in funding to even rebuild schools to basic operational standards let alone energy efficiency requirements. However, due to rising energy costs and the CRC Energy Efficiency Tax, carbon reduction is a key priority for all large organizations.

At present there is no additional funding or time allocation to support the iterative process needed for Low Carbon Designs. Further the business case for such solutions is based on the life-cycle savings. The study establishes that people controlling the cost plans (including clients) are unaware of the benefits of life cycle costs of low carbon designs and tend to base their judgements on capital costs. This trend is often amplified in Local Authorities who make the initial capital investment in the building but do not share the benefits of reduced energy costs with the schools. This prohibits Local Authorities to plan and invest in long term carbon reduction measures. Further current energy standards are not adequately equipped to drive low carbon technologies. This includes BREEAM that does not incentivise off-site low carbon technologies which offer more economy of scale.

The importance of predicting accurate or close to accurate energy consumption is due to the impact of energy on budget allocations for carbon and energy. Since schools form a significant part of a Local Authority's carbon emissions and a substantial part of the national emissions from building stock, their "performance in use" greatly impacts the local and national carbon reduction agenda and the Local Authority's financial liabilities. Current practices based on EPBD's Energy Performance Certificates and Part L compliance mechanisms do not include non-regulated loads. Designing low carbon schools is an iterative process where non-regulated loads have a substantial impact on the total energy consumption as well as the indoor air quality in building. Heat emissions from such equipments have an impact on the heating ventilation and cooling demand of the building. Their exclusion underestimates the energy forecast of the building and provides an unrealistic picture of the thermal comfort and building service solution. In addition the use of the standardized NCM profiles inputs anomalies within the model. The exclusion of after-hours use further hampers the energy prediction. Behavior of occupants towards energy use is a variable function and difficult to predict. However, it is one aspect that can be managed and if the energy model could be used to predict accurate performance under ideal behavior then successful approaches to carbon reduction could be established

All these factors put together lead to a cumulative miscalculation in the anticipated carbon reduction from the building and in turn the school stock, thus significantly affecting carbon targets set by Local Authorities. The current Building Regulations compliance mechanism while supporting understanding of performance against a notional building does not reflect the actual performance of the building in operation both in terms of thermal comfort or energy consumption. This emphasizes the need for appropriate measures both in terms of regulation and process for predicting energy consumption accurately. It is essential that actual energy consumption models and thermal comfort studies become essential deliverables in the design process. Building energy modelling must be based on total loads including unregulated loads and total school hours rather than core school hours. In order to be able to best inform the process design and energy modelling need to be combined in an iterative process that facilitates robust design decisions in terms of building performance and energy consumption. The current procurement frameworks and capital programme arrangements do not facilitate this. Future building programmes must be able to address this issue to facilitate carbon reductions in schools.

Non-regulated loads not only impose a challenge to energy consumption of the buildings but also contribute to overheating schools. With trends shifting from ICT Suites to ICT rich learning zones, managing heat emissions and energy consumption from such equipments is one of the biggest challenges facing education buildings. This is further substantiated by POE nationally. In the POE conducted on five low carbon schools, introduction of ICT into the curriculum and the multiple uses of buildings were partially responsible for poor performance in the studied schools [13]. In the studied schools the use of minimum design standards has led to the adoption of technology to ensure that acoustic and thermal environments are maintained usually in the form of central air handling units [13]. Complemented by such issues, the current BB101 guidelines for overheating in schools prescribing single values of temperature rather than ranges, severely inhibits the scope for natural ventilation solutions. BB101 also does not clearly prescribe the correct methodology for use of appropriate profiles. The use of the standardized NCM profiles builds in errors that increase the risk of overheating in operation. In addition the unpredictable nature of natural ventilation solution and onerous contracts further push designers toward mechanical ventilation solutions that are energy intensive. Short project delivery timelines, financial limitations and lack of adequate knowledge with the design industry to design successful passive building solutions is further prohibitive.

School buildings do not have a year round use. The energy demand with the exception of peak seasons is quite intermittent, characterized by spikes, non steady load restricted to shorter periods occurring few times a day at the most. In energy efficient buildings heating demand is further reduced and compensated by equipment, occupants and solar gains. Most low and zero carbon technologies become thus unsuitable for schools due to their intermittent nature of annual demand. Systems such as Biomass boilers and CHP are slow response systems and are uneconomical to address complete loads. This risk could be partially minimized by adding large thermal stores, however without adequate heat loads they prove to be inefficient and expensive. These solutions are thus best optimized when they are a part of larger energy sharing or district heating network. However BREEAM and local policies do not incentivize off-site low/ zero carbon solutions.

Post Occupancy Evaluations of newly built and refurbished schools in UK indicate that schools in England are consuming close to 2.5 times higher energy than predicted. This is largely due to the difference between the increase in use of the building and equipments and the behavior of the occupants from that predicted during design. In order for buildings to truly function as low carbon buildings a rigorous framework for zoning, smart metering and sub metering will have to be adopted. This will further need to be complemented with behavioral engagements with end users and incentives within contracts for facility managers.

Conclusion

Rising energy prices and carbon tax provide a considerable threat to Local Authorities and Schools. These however also tremendously incentivize the need for more energy efficient buildings. A large part of the current school building stock in UK is beyond its life-cycle and requires repairs and efficiency measures. Moreover, they are also often unsuitable to provide spaces for education today and prove to be a health and safety risk in terms of indoor air quality and a financial liability with respect to providing heating, ventilation and cooling. Trends have shown that such issues are aggravated due to the increase in ICT and other non-regulated loads in the buildings and an increase in after hours use. In a world where it is essential to reduce energy consumption, new UK schools are consuming up to 2.5 times higher energy and pose a considerable challenge in terms of overheating.

Designing schools to be energy efficient is a primary need and emphasis will always have to be placed on an appropriate building fabric design and energy efficient building service solution. This however by itself will not deliver Low Carbon Buildings. Differences between actual and predicted energy consumptions show that the issue is much larger than the building design. For schools to be truly successful examples of low carbon solutions an added framework for supporting them during their operation will be necessary. Better solutions in terms of incentivizing schools to manage facilities better and engage with the behavior of the occupants for energy reduction. Improved zoning; smart metering and sub-metering that can provide end-users a closer visibility, control and engagement with the energy being used. It will also support them in identifying the source of energy wastage and also involve such practices in the day to day delivery of education, thus embedding the culture of energy saving in the hearts and minds of future generation. Further study is needed to ensure that the increase in non-regulated energy and extended buildings use could be managed in a way to reduce overall carbon emissions across the cities.

Building regulations currently ensure the provision of low carbon buildings only to an extent by comparing the designed building to a nationally standardized low carbon building. At present there are no measures to incentivize the performance in operation or even calculation of predicted optimized energy consumption of the building. A wider approach will be needed to address this issue that should cover issues of policy, regulations, design processes and contracts to enable truly low carbon buildings.

References

[1] http://www.decc.gov.uk/en/content/cms/emissions/crc_efficiency/my_org/my_org.aspx

[2] Department for Energy and Climate Change. Climate Change Act 2008, The Stationery Office Limited, London, UK. Can be downloaded at http://www.legislation.gov.uk/ukpga/2008/27/contents

[3] Department of Trade and Industry. Energy White Paper 2003: Our Energy Future: Creating a Low Carbon Economy, The Stationary Office, London, UK. Can be downloaded at http://www.decc.gov.uk/en/content/cms/legislation/white_papers/white_paper_03/white_paper_03.aspx

[4] Department of Children, Schools and Families. Carbon Management Strategy for Schools: Second Consultation paper 2009. Can be downloaded at http://www.education.gov.uk/consultations/

[5] Carbon Trust. Focus on Local Authority School Estates, Carbon Trust, London UK 2011

[6] Department of Trade and Industry 2003. *Energy White Paper: Creating a Low Carbon Economy,* The Stationary Office, London, UK. Can be downloaded at http://www.decc.gov.uk/en/content/cms/legislation/white_papers/white_paper_03/white_paper_03.aspx

[7] Directory of UK Local Authorities, available at http://www.direct.gov.uk/en/Dl1/Directories/Localcouncils/index.htm

[8] Norbäck D., and K. Nordström. *Sick Building Syndrome in relation to air exchange rate, CO(2), room temperature and relative humidity: An experimental stud. International Archives of Occupational Environmental Health* (2008) 82(1): p. 21-30 2008. Can be downloaded at http://www.springerlink.com/content/f23532l427730415/

[9] Wargocki P., and D.P. Wyon. *Research Reports on effects of HVAC on student performance,* ASHRAE Journal 2008, vol. 48 (10), p. 22-28

[10] Coley and Greaves. *The effects of low ventilation rates on cognitive function of a primary school class,* International Journal of Ventilation 2004, vol. 6, pg. 107-112. Can be downloaded

from
http://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/ClientForums/Schools/Events/Archive/2005/LearningEnvironments/VentilationRatesInSchools.pdf

[11] Shaughnessy, R.J., Haverinen–Shaughnessy, A. Nevalainen, and D. Moschandreas. 2006. *A preliminary study on the association between ventilation rates in classrooms and student performance. Indoor Air, Vol* 16(6), p. 465–8.can be downloaded at http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.2006.00440.x/full

[12] Bak'o-Bir'o, Z., N. Kochar, D.J. Clements–Croome, H.B. Awbi, and M.Williams. *Ventilation rates in schools and learning performance*. Proceedings of CLIMA 2007—WellBeing Indoors, The 9th REHVAWorld Congress, Helsinki, Finland, 2007 880 pp. 1434–40.

[13] Pegg I., A. Cripps, and M. Kolokotroni. *Post Occupancy Performance of five low energy schools in the UK,* ASHRAE Transaction 2007, Vol 113 p. 3- 13. Can be downloaded from http://www.thefreelibrary.com/Post-occupancy+performance+of+five+low-energy+schools+in+the+UK.-a0172688600

[14] http://www.carbonbuzz.org/evidencetab.jsp

[15] Mumovic, D., J. Palmer, M. Davies, M. Orme, I. Ridley, T.Oreszczyn, C. Judd, H.A. Medina, G. Pilmoor, C. Pearson, R.Crithlow, and P. Way. *Winter indoor air quality, thermal comfort and acoustic performance of newly built schools in England.* Building and Environment *Vol* 44(7): p. 1466–77. Can be ordered from http://www.sciencedirect.com/science/article/pii/S0360132308001649

[16] Department for Education and Skills 2004. *Energy and water benchmarks for maintained schools in England: 2002–2003*. London, UK. Can be downloaded from http://www.education.gov.uk/rsgateway/DB/SFR/s000449/sfr05-2004.pdf

[17] Chartered Institute of Building Service Engineers. *TM46: Energy Benchmarks*. London, UK can be ordered at http://www.cibse.org/index.cfm?go=page.view&item=1246

[18] The Building Services Research and Information Association. A special report for the 2007 BSRIA briefing: Primary School Carbon Footprinting, January 2008. Can be downloaded from http://www.oecd.org/dataoecd/22/10/41449230.pdf

[19] Department for Education and Skills, 2006. Schools for the future; design of sustainable schools – case studies. The Stationary Office, London, UK

[20] DCSF 2007. *The Children's Plan,* Department for Children Schools and Families, The Stationary Office, London, UK. Can be downloaded from http://www.nationalschool.gov.uk/policyhub/news_item/children_plan07.asp

[21] Spending Review 2010. HM Treasury. Can be downloaded from http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/documents/digitalasset/dg_191696.pdf

[22] DCSF, March 2010. Road to Zero Carbon: Final Report of the Zero Carbon Task Force, Department of Children Schools and Families, Crown Copyright, London, UK

[23] Sebastian James. Review of Education Capital, January 2011. Can be downloaded from http://media.education.gov.uk/assets/files/pdf/c/review%20of%20education%20capital.pdf

[24] Office of the Deputy Minister (ODPM). 2006. *Building regulation, approved document part L2A. Conservation of fuel and power in new buildings other than dwellings*. The Stationery Office, London, UK

[25] DfES. 2006. *Building Bulletin 101 Ventilation of school buildings*, Department for Education and Skills, London, UK

Latest developments of electricity consumption and efficiency trends in the tertiary sector in the European Union

Bettina Hirl, Paolo Bertoldi

Joint Research Centre of the European Commission, Institute for Energy and Transport (IET), Ispra, Italy

Abstract

In 2005 the Joint Research Centre of the European Commission (EC-JRC) started an in-depth survey of the electricity end-use consumption and energy efficiency trends in order to assess the energy efficiency potential in the European Union Member States (EU-27)[1]. The survey is updated every two years, the last one being carried out in early 2012.

The paper presents the latest trends in electricity consumption and energy efficiency in the tertiary sector. In the first part, general trends in total energy, electricity and gas consumption in the tertiary sector incl. growth rates are presented. The focus of the paper is on electricity consumption. In the second part, important electricity end-use appliance groups of the tertiary sector are analysed including office and street lighting, computers and imaging equipment and commercial air-cooling appliances.

Accounting for electricity consumption is a very important step in the development of energy policies, but so far consumption analyses have been neglected or underestimated in policy development and related research. This paper presents the main results and conclusions for the tertiary sector of the latest updated in-depth survey.

Introduction

Total final energy, gas, and electricity consumption in the EU-27 continue to increase. In the last 20 years (1990-2010) they grew by 6.29%, 30.92%, and 17.25% respectively. Also in the tertiary sector, final energy, gas, and electricity consumption are still rising. The sector is becoming more important every day, growing substantially in the last years. There is a great potential for energy savings in the tertiary sector. Policies to promote energy efficiency in the EU such as ecodesign measures, energy labelling and building codes will help to realize these potentials. As many of the measures have still to be implemented, the success of the policies will only be visible in the next few years. Looking at the electricity consumption breakdown in the tertiary sector, we see that lighting (office and street lighting), water and space heating, and ventilation are the most important end-users of electricity. Ecodesign measures and labelling for lighting have been implemented successfull whereas measures fror ventilation still need to be implemented. Office equipment and computers are important end-users of electricity in the tertiary sector and their consumption is growing. The potential for savings there is important and policies need to be implemented in the near future to follow the rapid growth of these markets.

Overview of recent energy efficiency policy developments in the EU

Energy efficiency has become one of the core policy goals in the European Union. In this chapter, we will give a short overview of recent policy developments such as product policy and building performance standards.

EU product efficiency policy focuses on two main approaches: 1) labelling and standard product information and 2) minimum energy performance standards (ecodesign requirements). In the last two years two new important directives concerning product energy efficiency have been implemented:

---

[1] The European Union comprises the following 27 countries: Austria (At), Belgium (Be), Bulgaria (Bg), Cyprus (Cy), Czech Republic (Cz), Denmark (Dk), Estonia (Ee), Finland (Fi), France (Fr), Germany (De), Greece (Gr), Hungary (Hu), Ireland (Ie), Italy (It), Latvia (Lv), Lithuania (Lt), Luxembourg (Lu), Malta (Mt), Netherlands (Nl), Poland (Pl), Portugal (Pt), Romania (Ro), Slovak Republic (Sk), Slovenia (Sl), Spain (Es), Sweden (Se), and United Kingdom (UK).

Directive 2010/30/EU on labelling *(Directive on the indication by labeling and standard product information of the consumption of energy and other resources by energy-related products*) and Directive 2009/125/EU on Ecodesign ((*directive establishing a framework for the setting of eco-design requirements for energy-related products*). Both directives are new versions of already existing directives (Directive 92/75/EEC for labeling and Directive 2005/32/EU for design of energy-using products.

The Eco-design Directive is a framework directive. This means that the directive does not set specific eco-design requirements for specific products but it sets a general framework for specific requirements. In the Eco-design Directive the conditions and criteria for the eco-design requirements through subsequent implementation measures are defined. The directive also defines the product categories to which the eco-design requirements will be applied.

Current situation of ecodesign measures in the tertiary sector:

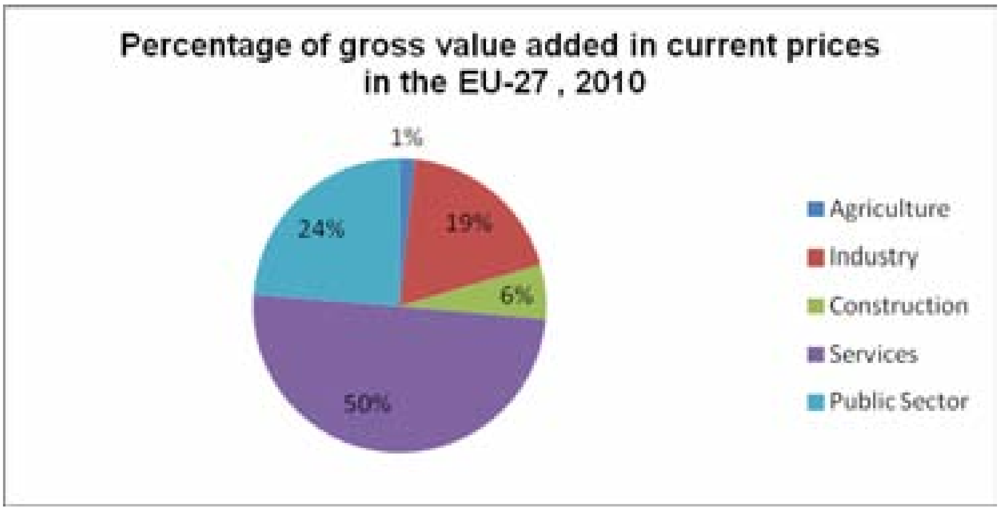
Product group	**Eco-Design Measure**
Boilers	not implemented yet
Circulators in buildings	implemented 07/2009
Commercial refrigerators and freezers	not implemented yet
Computers and monitors	not implemented yet
Electric motors	implemented 07/2009
External Power Supplies	implemented 04/2009
Imaging equipment	not implemented yet
Network standby losses	not implemented yet
Office and street lighting	implemented 03/2009
Ovens , hobs and grills	not implemented yet
Simple Set-Top Boxes	implemented 02/2009
Standby and off Mode	implemented 12/2008
Tertiary airconditioning	not implemented yet
Ventilation fans	not implemented yet

According to the new labelling directive, from December 2011 onwards new energy efficiency classes on the basis of the Energy Efficiency Index (EEI) are be added (e.g. A+, A++, etc.) and the coverage is extended to non residential equipment.

Apart from product policy, building performance standards have been implemented in the EU in order to promote energy efficiency. The Energy Performance of Building Directive was adopted in May 2002 (and the recast in 2010) and calls for increased national regulation for energy efficiency in new and renovated houses. The directive also sets the framework for national requirements for building systems, such as heating systems and larger ventilation systems. In July 2012, the new EPBD Directive shall be implemented.

Energy consumption trends in the tertiary sector in the EU

Fig. 1: Gross value added to GDP of the tertiary sector, 2010 (source Eurostat)

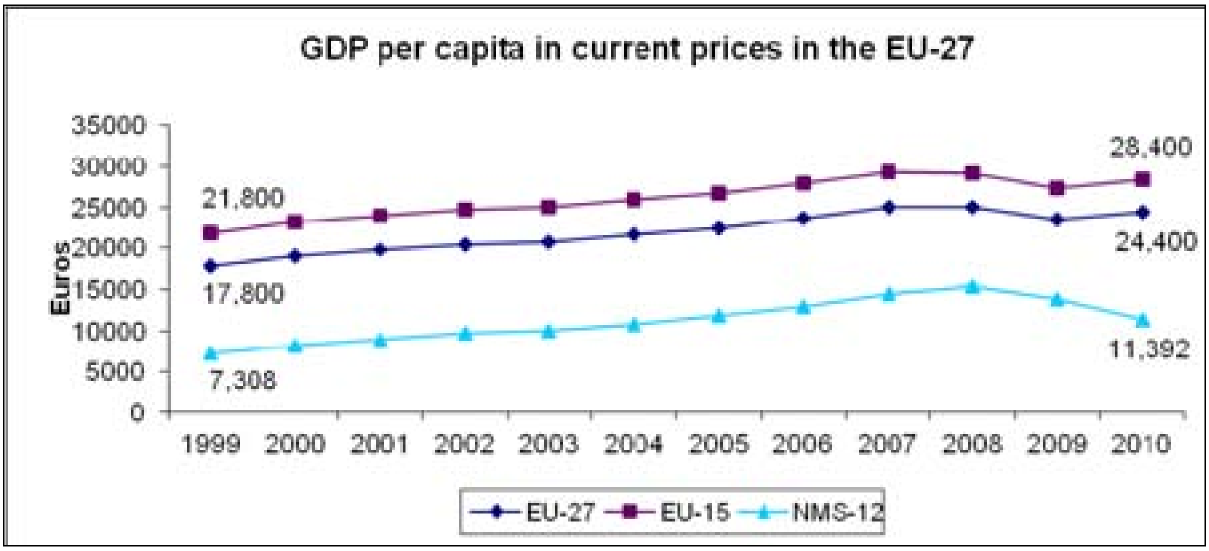


The tertiary sector accounts for a large share of GDP in the European Union. The tertiary sector in the European Union accounted for 50% of total gross value added (GVA) (in current prices) in 2010. If we also include the public sector this share is rising up to 74% - almost three quarters of the total value added to the economy. The importance of the tertiary sector is expected to further grow during the next years.

When looking at energy consumption statistics it is important to consider other factors influencing energy consumption such as economic development and weather conditions. No quantitative, econometric analysis of energy consumption and these factors is presented in this paper. Therefore, we cannot draw conclusions on dependencies or correlations between these factors and energy consumption trends. It is nevertheless helpful to have the factors in mind when trying to understand consumption patterns.

Looking at GDP per capita (in current prices, 2010) in the EU-27 we can see that it has been growing in the period between 1999 and 2010 from 21'800 € up to 28'400 €. The effect of the economic and financial crisis can be seen in the year 2009 when GDP per capita drops. In the 12 New Member States (NMS-12), GDP per capita continued to decrease between 2009 and 2010 whereas it grew again in the EU-15 and in the EU-27.

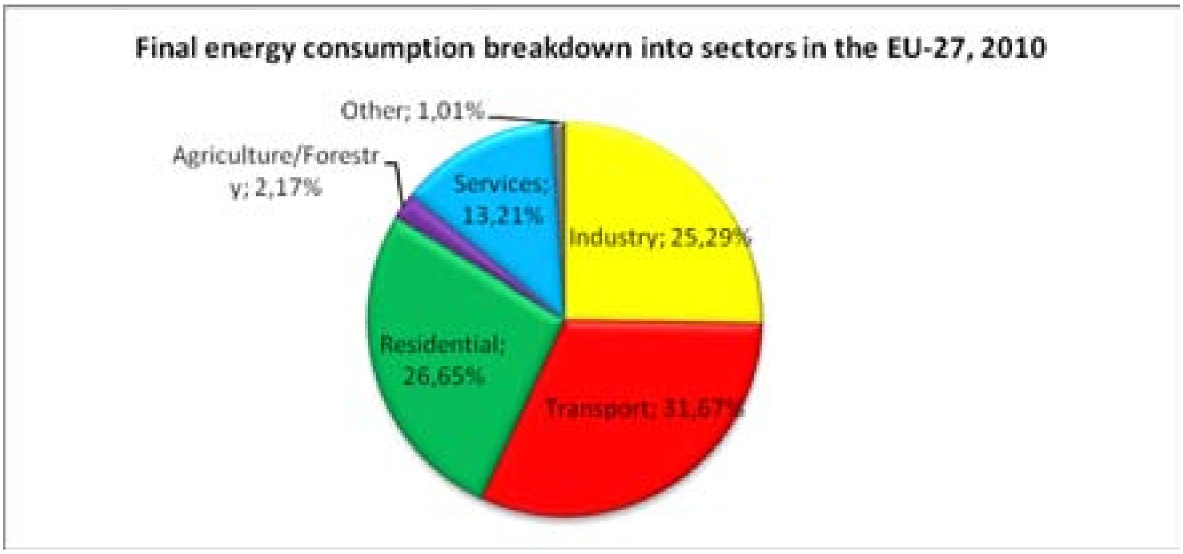
Fig. 2: GDP per capita in current prices in the EU-27 (source Eurostat)



Energy consumption trends

Final energy consumption in the tertiary sector has been growing during the last years. In 1999, total final energy consumption of the services sector in the EU-27 was 123.476 ktoe whereas in 2009 the sector consumed 143,295 ktoe and in 2010 this figure grew to 152,338 There is a large difference in consumption between the EU-15 (130,064 ktoe in 2010) and the NMS-12 (22,273 ktoe in 2010)

Fig. 3: Energy consumption breakdown (source Eurostat)

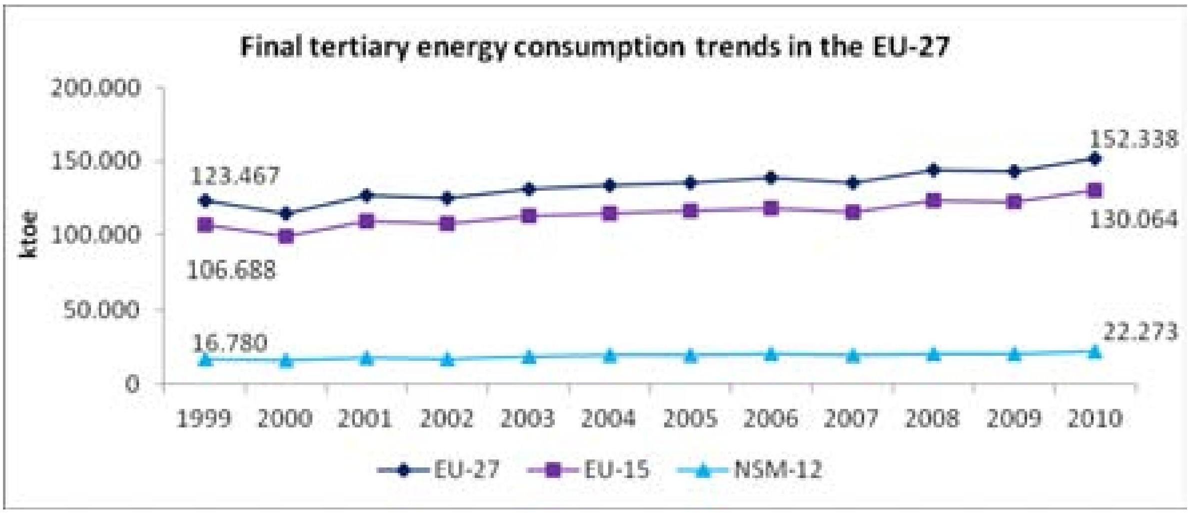


At the moment we cannot see a decreasing trend in tertiary energy consumption. However between 2008 and 2009, energy consumption in the services sector fell from 144,074 ktoe in 2008 to 143,295 ktoe in 2009. This decrease is very likely a result of the financial and economic crisis in 2009. GDP per capita increased again between 2009 and 2010 and so did final energy consumption in the tertiary sector. Results of energy efficiency measures and policies are not visible yet will only be seen in some years from now.

Between 1990 and 2010 total energy consumption in the tertiary sector in the EU-27 grew by 40.42%. Most of this growth took place in the EU-15 where consumption in the tertiary sector increased by 44.28% in this period whereas consumption in the NMS-12 only grew by 21.46%. The picture slightly changes when looking at the growth in consumption in the period 2000 to 2010. During this time, energy consumption in the tertiary sector in the EU-27 grew by 32.38%. In the EU-15 the growth in consumption was 31.79% whereas the growth in the NMS-12 was 35.94%. In the EU-27, the EU-15, and the NMS-12 energy consumption in the tertiary sector reached its highest level in 2010 with 152,338 ktoe, 130,064 ktoe, and 22.273 ktoe respectively.

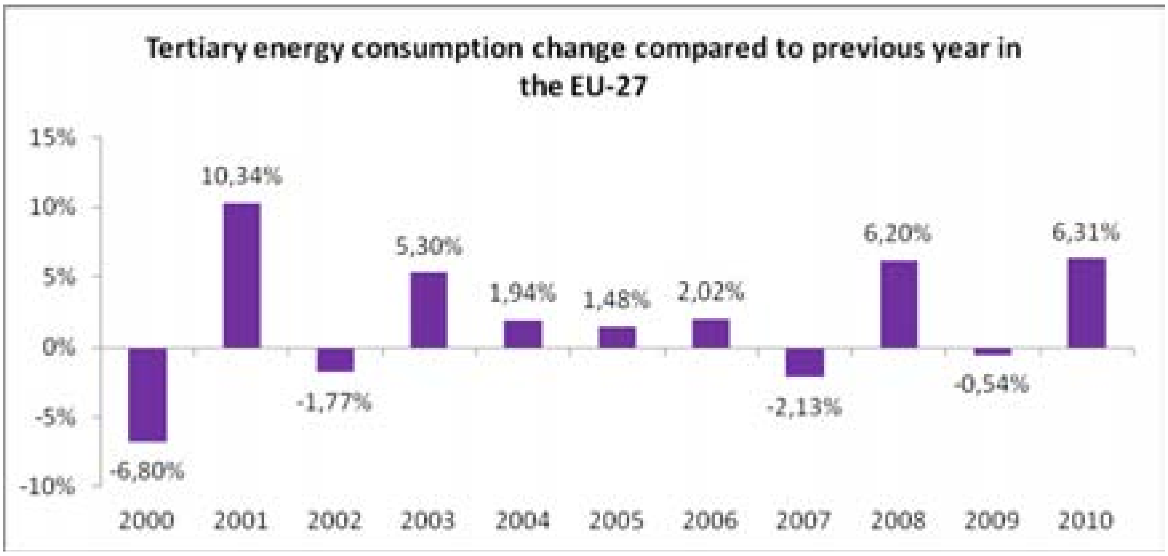
In the last five years energy consumption in the tertiary sector continued to grow. In the EU-27 the growth rate between 2005 and 2010 was 12.12%, in the EU-15 it was 11.77%, and in the NMS-12 consumption increased by 14.20%.

Fig. 4: Final tertiary energy consumption in the EU-27 (source Eurostaat)



Between 2008 and 2009, final energy consumption in the tertiary sector fell by -0.54%; between 2009 and 2010 it grew by 6.31%. Looking at the annual growth rates of the last ten years (2000-2010), we cannot find a clear trend for tertiary energy consumption. Between 2003 an 2007 it looked like tertiary energy consumption growth rates were decreasing. The growth rates etween 2007 and 2008 and between 2009 and 2010 are, however, contrary to this trend.

Fig. 5: Residential energy consumption growth trends - change in % to previous year (source Eurostat, JRC)



Electricity consumption trends

The tertiary sector had a share of 29.41% of total electricity consumption in the EU-27 in the year 2010. It was therefore the third biggest sector in electricity consumption after the industry sector with 36.47% and the residential sector with 29.71%. The share of the residential and the tertiary sectors were almost equal in 2010.

Fig. 6: Final elecricity consumption breakdown into sectors in the EU-27 (source Eurostat)

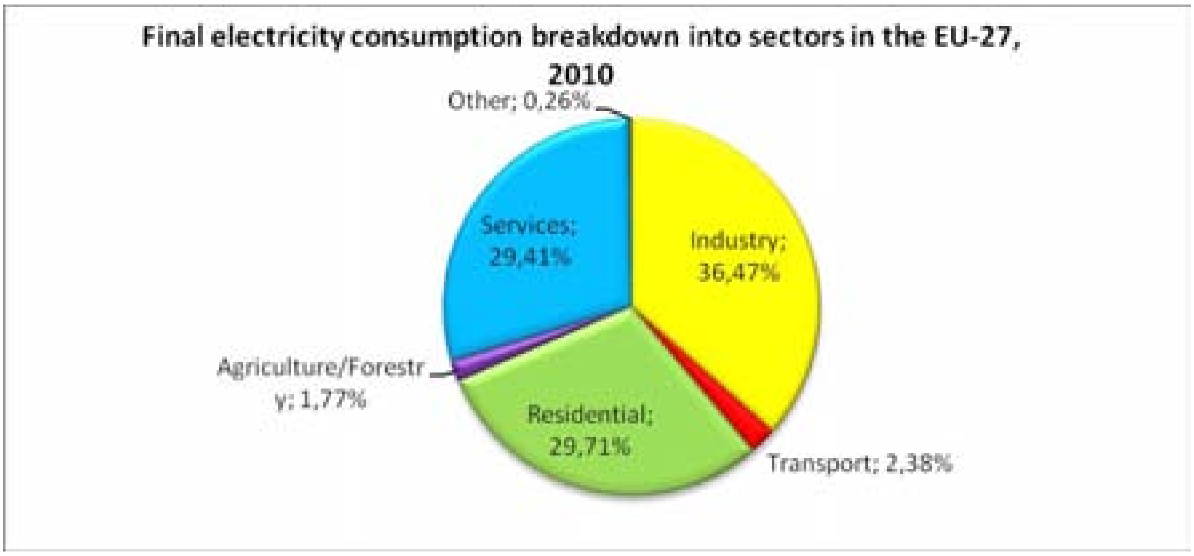
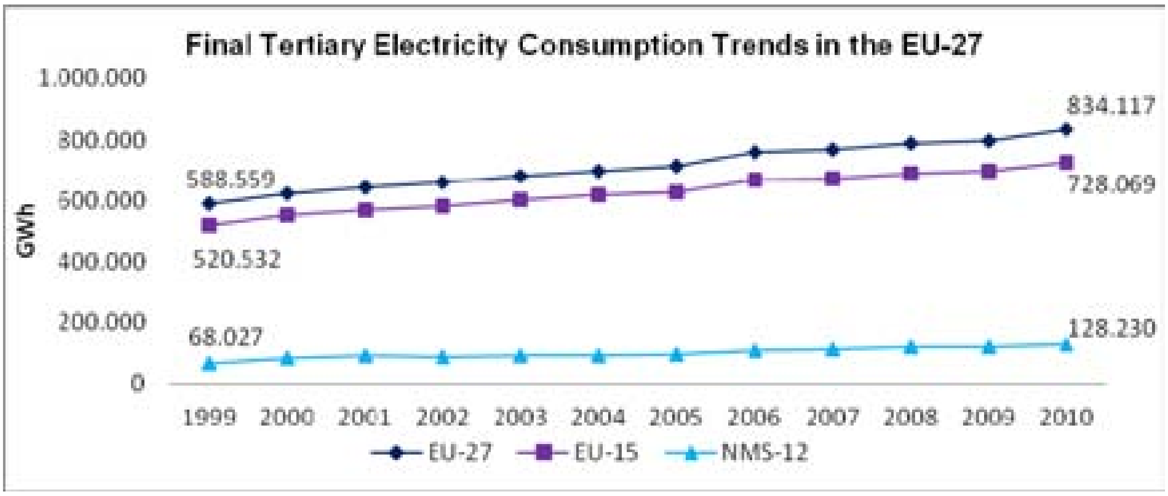


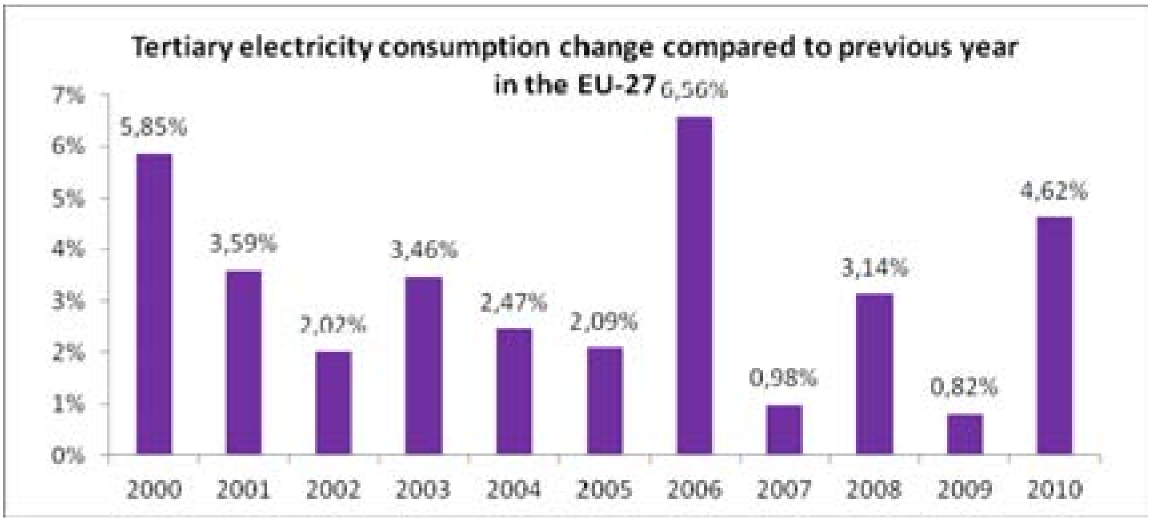
Fig. 7: Final tertiary electricity consumption in the EU-27 (source Eurostat)



Electricity consumption in the tertiary sector is continuing to grow. Electricity consumption grew from 588.559 GWh in 1999 to 834,117 GWh in 2010 in the EU-27. In the EU-15 electricity consumption was 520.532 GWh in 1999 and 728,069 GWh in 2010, and in the NMS-12 consumption grew from 68.027 GWh in 1999 to 128,230 GWh in 2010.

Between 1990 and 2010 electricity consumption in the tertiary sector has increased by 92.61% in the EU-27. In the NMS-12, the increase in consumption was 142% and in the EU-15 the increase was 58.57%. This increase can be attributed to above average growth rates in 2006 (6.56%) and 2010 (4.62%), Between 2000 and 2010 electricity consumption in the tertiary sector in the EU-27 increased by 33.89% compared to 31.92% in the EU-15 and 53.88% in the NMS-12. Growth rates were below average in the years 2007 (0.98%) and 2009 (0.82%). The relatively small growth rate in 2007 can be attributed to a large extent to the warm weather in 2007 (and hence less heating) whereas the one in 2009 is likely related with the financial and economic crisis.

Fig. 8: Growth rates (% change compared to previous year) of tertiary electricity consumption in the EU-27 (source Eurostat, JRC)



Gas consumption trends

Between 1990 and 2010 final tertiary gas consumption in the EU-27 grew by 71.41%. Between 2000 and 2010 tertiary consumption grew by 60.38%. During the last five years tertiary consumption grew by 9.60% (2005-2010) and only by 1.57% between 2004 and 2009. The high growth rates are to a large extent caused by a high growth in consumption between 2009 and 2010 (9.98%). There is a drop in consumption in the year 2007 which can be explained with warmer temperatures during this year (and hence less heating degree days and less gas consumption). If we look at absolute consumption figures we find that total gas consumption in the EU-27 had a peak in the year 2004 with a total consumption of 285.560 ktoe. In the year 1990 total gas consumption was 229.009 ktoe and twenty years later in 2009 the consumption level was 252.577 ktoe. In the tertiary sector there was a peak in consumption in the year 2005 with a total consumption of 43.062 ktoe and consumption reached its highest point in 2010 with 47,039 ktoe. In 1990 tertiary gas consumption was 26.965 ktoe and the consumption level in 2009 was 42.262 ktoe. Since the year 2005/2006 we saw a decreasing trend in gas consumption until the year 2010.

Fig. 9: Final tertiary gas consumption trends in the EU-27 (source Eurostat)

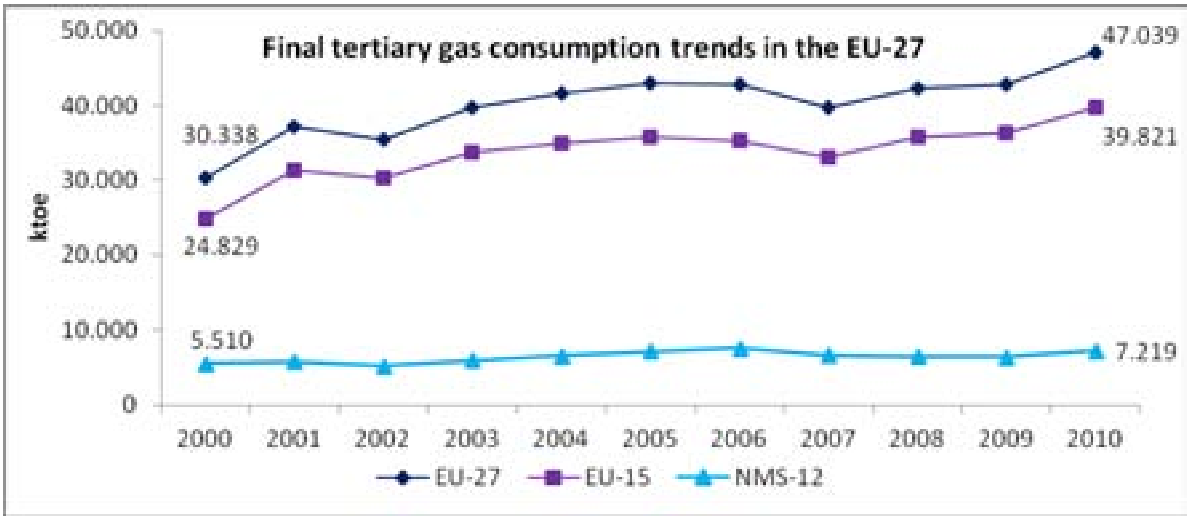
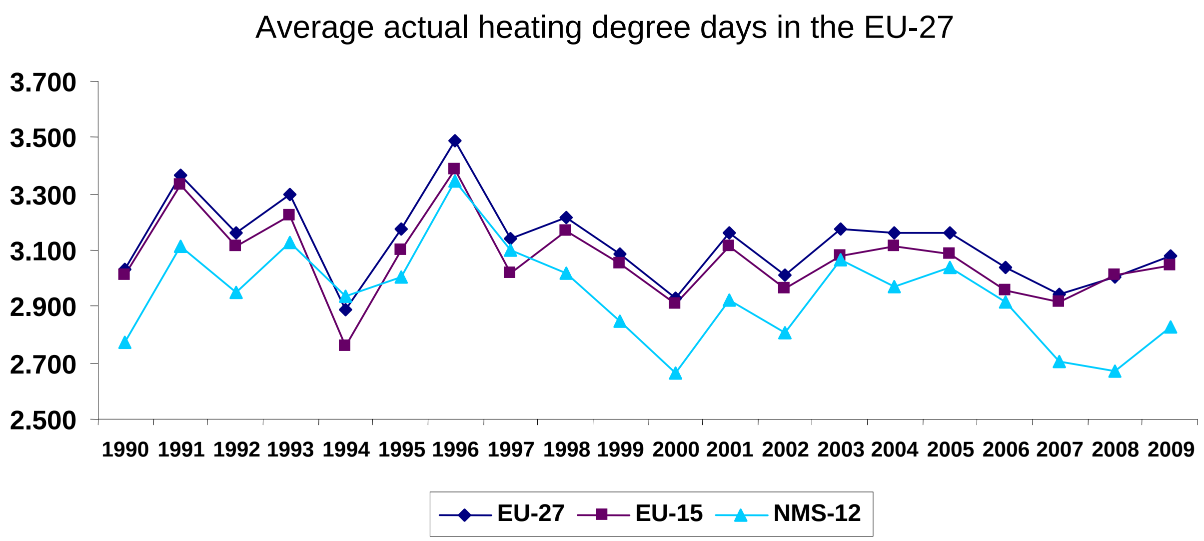


Fig. 10: Actual heating degree days in the EU-27 (source Eurostat)

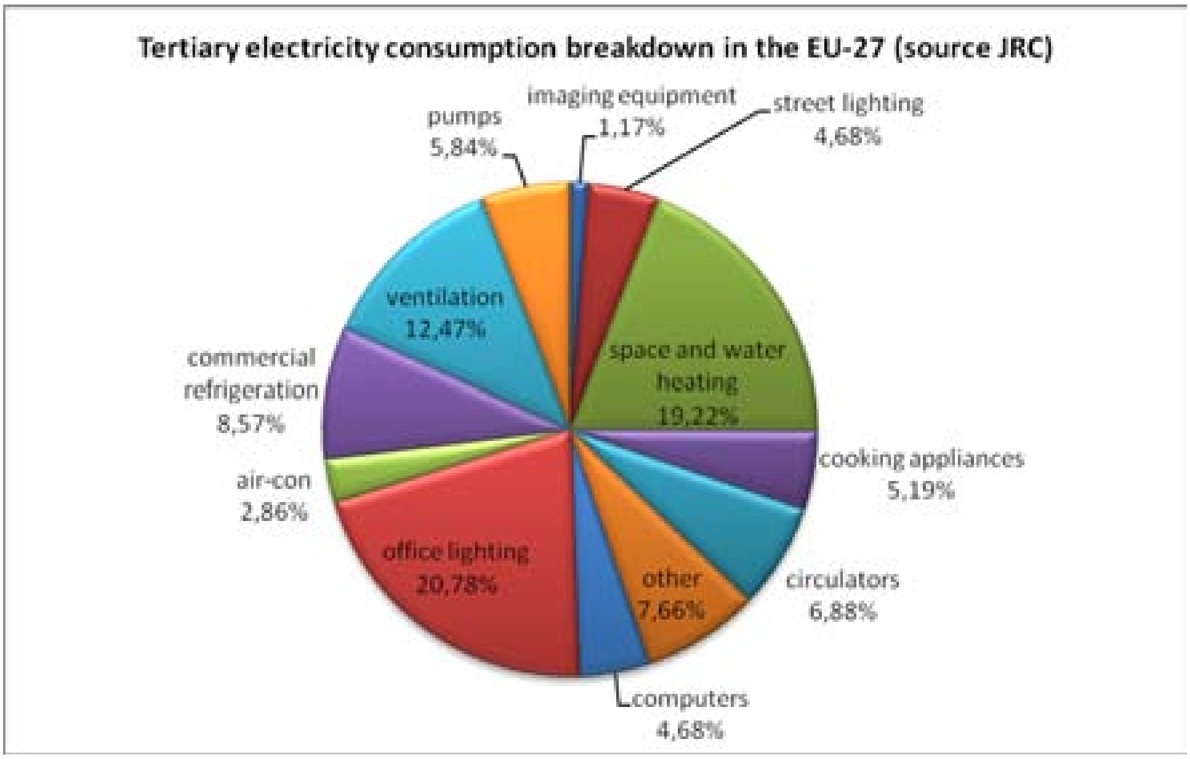


Electricity end-use in the tertiary sector

Electricity consumption breakdown

There is much less reliable data available for individual electricity end-uses in the tertiary sector than in the residential sector, and only a few sources attempted to divide total electricity consumption among different end-uses. The largest electricity consumers in the EU-27 tertiary sector are lighting in offices (20.78% and 25.46% together with street lighting), electric space and water heating systems (19.22%), ventilation (12.47%) and commercial refrigeration (8.57%).

Fig. 11: Tertiary electricity consumption breakdown in the EU-27 (source JRC)



Office and street lighting

According to the Eco-design preparatory studies for office and public lighting, the EU-27 office lighting consumption is the biggest share of total consumption in the tertiary sector with 21.57%, representing 164 TWh in 2007. The street outdoor lighting takes a share of 4.73% of the overall tertiary sector electricity consumption, representing 36 TWh in 2007. These figures are estimated to be almost constant in 2009 with a trend to decrease in the next years considering the Eco-design measures, energy labelling and also voluntary programmes.

The preparatory study estimates the market share in 2004 of linear fluorescent lamps (LFLs) at 16% of total lamp sales and CFLs at 6%. The annual increase in 2004 was 4.2% for LFLs and 8.3% for CFLs [BER2009, TIC2007]. Existing data for the domestic sector show an increase in CFLs over the last years. Between 2006 and 2010 an increase of 45% in sales of CFLs in the domestic sector has been estimated. Therefore, it can be assumed that CFL sales are also increasing substantially in the tertiary sector.

Looking at annual sales of T5 and T8 fluorescent tubes, we can see that sales have increased during the last five years (2006-2010). Sales of T5 tubes increased by 70% during this period and sales of T8 tubes increased by 10% in the same period [4E mapping]. The ecodesign measure for office and street lighting established minimum efficacy requirements for both T5 and T8 tubes.

Apart from the Eco-Design measures and the energy labelling, a voluntary programme, the European Quality Charter for LED[2] has been implemented. The European Quality Charter for LED was developed in 2010 on the initiative of the European Commission DG JRC to support the European initiatives for the promotion of efficient lighting in the residential sector [1].

The scope of the present version of the LED Quality Charter is limited to LED lamps intended primarily for use in the residential sector. At this stage the European Quality Charter for LED does not include LED modules, luminaries and lamps specific for use in the commercial sector. This limitation is due to the urgent need to support customers replacing banned incandescent lamps (GLS and some halogen lamps), and other promotion programmes at national or local level (e.g. White Certificates) [EC2011a].The goal of the European LED Quality Charter is to further increase the penetration of high quality and efficient LEDs across the EU and thus contribute to the goals of the EU energy and environmental policies [1].

Office equipment and data centres

Information and communication technologies (ICTs) are among the fastest growing electricity end-use in the residential and tertiary sector. In 2009, the ICT market in Europe reached the size of 849 billion EUR, in 2010 it grew to 854 billion EUR [2]. Worldwide, the ICT market reached 2629 billion EUR in 2009 and 2658 billion EUR in 2010, the European market accounts for 32% of the world ICT market [2]. The market is expected to continue growing substantially reaching a worldwide market volume of 3050 billion EUR in 2013 and 933 billion EUR in Europe in 2013 [2].

The size of the digital technology sector in Europe represents 4.5.% of EU aggregate GDP and even more in value added of digital technologies in other sectors is also accounted for [3]. In 2011, global IT revenues grew by 4.4% to 1.1 billion € [3]. The growth rate in the EU was almost 3% with Germany leading with 4% growth before France (3%) and the UK (2%) [3].

In the first quarter of 2010, consumers in Western Europe spent € 46.5 billion on technical consumer goods, meaning an increase of 2.7% in total compared to the same quarter in 2009 [4]. The information technology market, the second biggest market after consumer electronics, was worth € 11.5 billion in the first quarter of 2010 [4].

Broadband penetration continues to grow in the EU. From 18.2% in 2007, 21.7% in 2008, 23.9% in 2009 up to 25.6% in 2010. Only six years earlier, in 2004, the penetration rate was 4.9% [5]. As of mid

---

[2] More information on the LED Quality Charter can be found here:
http://re.jrc.ec.europa.eu/energyefficiency/LED_Quality_Charter/index.htm

2010, the EU-27 registered 128 million fixed broadband lines in comparison to 108 million in 2008, growing by 18.5% during these two years [5].

Personal computers, monitors and imaging equipment have been growing substantially during the last years. It is expected that this trend will continue. Based on the Eco-design studies for personal computers and computer monitors, JRC estimates that in 2007 some 48.5 million desktop computers and 59.3 laptop computers were installed in non-residential applications. Compared to the year 2005 the number of desktop computers grew by 6% and the number of laptop computers grew by almost 60% in two years time. For the period between 2007 and 2009 similar growth levels can be assumed leading to a stock of desktop computers of over 50 million and over 80 million laptop computers.

According to the Eco-design study, the EU-27 computer monitor stock in 2007 was around 13.3 million cathode ray tubes (CRTs) and more than 41 million flat panels. As in the case of television sets, flat panel monitors are growing very fast on the market (doubling the stock in only two years from 2005), replacing the out-dated CRT monitors. For 2009, it can be estimated that the stock in flat panel monitors has increased again significantly and will replace the CRT monitors completely in short time.

Growth in both laptop and flat-panel monitors has contributed to the decrease of the electricity consumption of computing office equipment reaching some 3.4% of the tertiary electricity consumption of around 23 TWh in 2007. For 2009 the share of office equipment in total electricity consumption of the services sector is estimated to have increased to over 4%.

Between 2006 and 2010 the Energy Star programme was implemented in the European Union.[3] The ENERGY STAR is a voluntary appliance specific label, identifying to consumers appliances that meet certain standards regarding energy efficiency. The EU ENERGY STAR Programme follows an Agreement between the USA Government and the European Union on the co-ordination of voluntary energy labelling of office equipment, approved by the EU Council in April 2003. The revised Energy Star technical specifications Version 5.0 for computers became effective on 1 July 2009 [6].

The number of manufacturers participating in the programme has increased significantly, from 16 companies in 2006 to 74 in 2010. It is estimated that without ENERGY STAR the electricity consumption of new office equipment sold in the EU in the last three years would have been approx. 67 TWh. ENERGY STAR succeeded in reducing this by around 11 TWh, i.e. by approx. 16 %. This translates into more than EUR 1.8 billionn saved on energy bills and 3.7 Mt of avoided CO2 emissions. It needs to be noted that these numbers represent a ‘snapshot’, i.e. they do not take into account the current impact of earlier (pre-2008) specifications, or the future impact of current specifications. If these two elements are taken into account, it is estimated that ENERGY STAR will succeed by 2020 in reducing the energy consumption of the installed base of computers, displays and imaging equipment in the EU by more than 30% [6].

In March 2007 the EU Code of Conduct for Data Centres was initiated. The Code of Conduct is a voluntary scheme within the EU that provides a platform to bring together European data centre owners and operators, data centre equipment and component manufacturers, service providers, and other large procurers of such equipment to discuss and agree on voluntary actions that will improve energy efficiency. The Code of Conduct (CoC), coordinated by the Joint Research Centre (JRC), proposes general principles and practical actions to be followed by all parties involved in data centres operating in the EU to result in more efficient and economic use of energy without jeopardising the reliability and operational continuity of the services provided by data centres.

The EU CoC for Data Centres is addressed to all buildings, facilities and rooms which contain enterprise servers, server communication equipment, cooling and power equipment and provide a form of data service. The CoC covers two main areas of energy consuming equipment in the data centres, IT loads and facilities loads, but considering the data centre as a complete system and being oriented on the optimisation of the IT system and the infrastructure in order to deliver the desired services in the most efficient manner.

---

[3] More information can be found under: http://www.eu-energystar.org/en/index.html

The first Code of Conduct on Data Centres Energy Efficiency (Version 1.0) from October 2008 entered into force at the beginning of 2009.

At the end of 2011 about 150 Data Centres were participating in the Code of Conduct. Since energy consumption of data centres is rising rapidly in Europe, the Code of Conduct is a very important initiative in order to slow down this development. In 2007, energy consumption of data centres was at around 56 TWh, this figure is expected to rise to 104 TWh in 2020 [7].

Ventilation, Fans, and Air-conditioning

Non-residential buildings refer to a broad range of building types, which have many similarities in the technologies used for ventilation, but could differ significantly in the way the building is used. The variety of applications range from concert halls in which fans are used only in the evening for a limited number of hours, to school building which might be in use only in the morning, over to office buildings where ventilation in mainly required during office hours. In addition, there are also workshops in which there is a three-shift production, making it necessary to operate the ventilation systems around the clock. As the ventilation is used to exchange the air and to remove heat, humidity and other contaminants, the required airflow varies typically over the year with higher ventilation rates during summer time [8].

According to the Eco-design preparatory study Lot11 for fans, the energy consumption in use represents the main environmental impact (more than 90%) and efficiency improvements of the fan product are possible with the same or reduced life cycle costs. The cumulative savings could be achieved by introducing minimum energy performance standards are estimated to be up to 30 TWh by 2020 [8].

The market for air-conditioning, ventilation and fans is still growing rapidly. Projected figures show that there should be continuous growth in sales of chillers, with a slow decline in first-time installation sales and an increase in replacement sales during the next years. The installed stock of air conditioning chillers might increase from around 180 GW in 2010 to around 240 GW in 2020 and 270 GW in 2025 [9]. Because chillers have long lifetimes of more than 20 years for medium and large capacity products, 75% of the 2025 stock should be composed of pre-2020 products. These products will be impacted by future Eco-design measures. The preparatory study estimates that the electricity consumption of the stock of Lot 6 air conditioning products was at least 74 TWh in 2010, acknowledging that the electricity consumption related to the heating function of reversible chillers is not included in this figure and should be around 15 TWh [8].

Air-conditioners and chillers have still a large potential for improvement by using the best available technologies, which encompass better individual component like EC motors for fans, larger heat exchangers, better part load control and optimizes part load designs. To maximize the potential benefits, the efficiency is to be judged on a seasonal performance standard, which is almost ready for air conditioning products covered by Lot 6.

There are four main types of ventilation systems: natural ventilation, fan assisted exhaust ventilation, fan assisted supply ventilation, fan assisted balanced ventilation [8]. The stock of central airconditioning products is expected to grow substantially during the next years. The stock in terms of cooling capacity is estimated to increase by around 700% between 1990 and 2025. Between 2005 and 2010 the increase is estimated to be of around 30% [8].

Conclusion

The tertiary sector continues to grow and has already become the biggest economic sector in terms of value added (GVA) in the EU. It accounts for around 13% of total energy consumption and for around 30% of total electricity consumption. Most of the electricity is consumed by office and street lighting, space and water heating, ventilation and commercial refrigeration.

In the last years important energy efficiency policies have been implemented across the EU. These include labelling and product information, ecodesign measures and building performance standards. For many appliances with big saving potential regulation still needs to be implemented.

As pointed out in the paper, total energy consumption, electricity consumption and gas consumption in the tertiary sector are still rising. Results of energy efficiency measures and policies are not visible yet and will only be seen in some years from now. For some appliances groups such as lighting and refrigerating we can already see the positive effect of efficiency policies. A thorough evaluation of efficiency policies (labelling and ecodesign measures) needs to be done after at least 5 years from now when effects can be seen and more product groups have been covered.

Table of figures

References

[1] European Commission, Joint Research Centre, EUROPEAN LED QUALITY CHARTER, February 2011

[2] IDATE-DigiWorld programme: " DigiWorld Yearbook 2010: Les enjeux du monde numérique", ISBN: 978-2-84822-258-5, 2010

[3] DIGITALEUROPE: European Competitiveness Report; European Information Technology Observatory 2006, March 5, 2009

[4] EITO, European Information Technology Observatory -a project of Bitkom Research GmbH, Press Release: "Global IT markets back on track for strong growth", 2011

[5] European Commission, COMMUNICATIONS COMMITTEE, Working Document, Subject: "Broadband access in the EU: situation at 1 July 2010", November 2010

[6] European Commission, COMMUNICATION FROM THE COMMISSION on the implementation of the ENERGY STAR programme in the European Union in the period 2006 – 2010, June 2011

[7] P. Bertoldi: "The European Programme for Energy Efficiency in Data Centres: The Code of Conduct", Presentation at DC Stakeholder Meeting, DG JRC European Commission, London, November 2010

[8] P. Bertoldi, B. Atanasiu: "Electricity Consumption and Efficiency Trends in European Union – Status Report 2009", European Commission DG Joint Research Centre,2009

[9] Armines France, Van Holsteijn and Kemna, Building Research Establishment: EuP Preparatory Studies Lot 6:" Airconditioning and ventilation systems", Draft Report on Task 2:" Market on ventilation systems for non residential and collective residential applications",May 2011.

Energy Consumption Analysis in the Service Sector

Georg Benke, Barbara Mayer[1], Mario Jandrokovic[2]

e7 Energie Markt Analyse GmbH

Abstract:

Whereas the energy consumption of private households (26 % of the total final energy consumption) is well documented and specified, there is only little information available about the energy use in service buildings. However, in order to elaborate appropriate instruments, to implement specific programs for energy efficiency in this sector or to evaluate the effects of energy saving measures, both detailed as well as structured information and data about the energy use are necessary. Within the scope of a project supported by the Austrian climate fund information about energy use and temporal demand in the service sector shall be developed.

Keywords: energy consumption, service sector, effective energy, load curve, energy balance

Starting situation

The residential and the service sector consume approximately 38 % of the final energy in Austria (419 PJ). Whereas the energy consumption of private households (26 % of the total final energy consumption) is well documented and specified, there is only little information and data available about the energy use in service buildings.

In order to elaborate appropriate instruments for the service sector which stimulate energy-efficiency-related measures, to implement specific programs for energy efficiency in this sector or to evaluate the effects of energy saving measures, both detailed as well as structured information and data about the energy use are necessary.

Against this background the actual climate fund project pursues the objective of scrutinizing the energy input in the service sector. The required information is elaborated within the scope of a both comprehensive and detailed analysis of energy consumption and analysis.

Setup and methodology of the project

In order to receive detailed data about the **energy consumption in the service sector, information about the** annual energy consumption **of 12,000 service companies** is collected. This survey forms a basis for the definition of benchmarks for individual branches and demand segments. Based on this, an analysis of effective energy use will be carried out in order to provide additional in-depth information about the different kinds and the levels of energy use as well as the temporal distribution of the energy demand.

Three different approaches are pursued contemporaneously, which are subsequently combined to a joint conclusion.

---

1 Statistik Austria, Agency for Spatial Economics, Energy; Vienna
2 Energieinstitut der Wirtschaft (Energy Institute for Business); Vienna

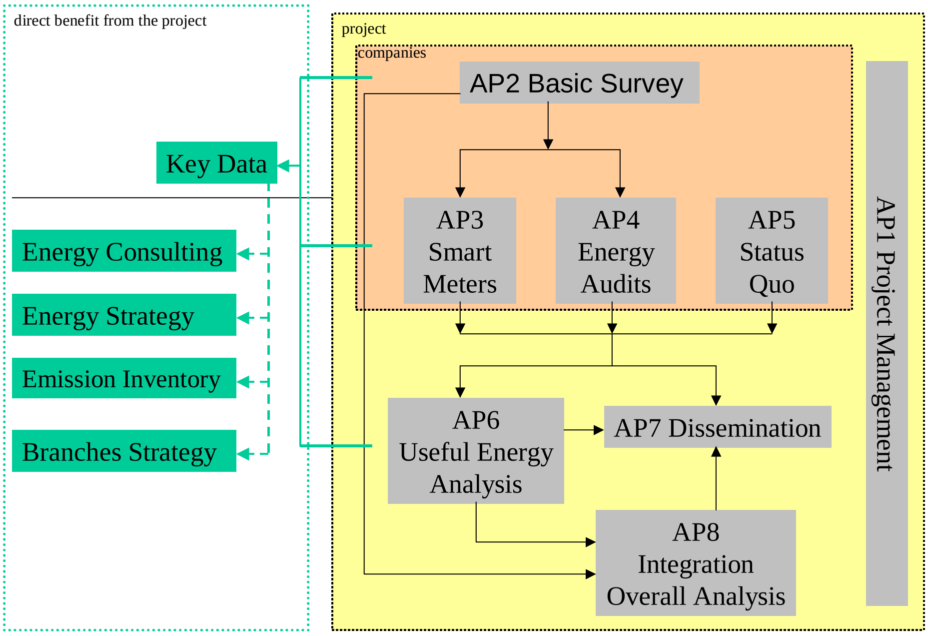


Figure 1: methodological basic structure of the project: connections between the (statistic) initial survey and the deepening analyses

Within these mutually-independent approaches the focus is drawn to the following aspects:

1. **Energy Audits**: The results of the nationwide energy efficiency consulting activities of the Energy Institute for Business (EIW) that are carried out within the scope of the climate fund's SME-initiative for energy efficiency increase are used as a baseline for the energy analysis in each branch. Detailed standardized information from more than 600 service companies is available. At the same time, the results will be integrated in the consulting process again; hence they are directly relevant for the market.

2. **Smart Meters Analysis**: Based on the existing energy controlling and monitoring system, the load profile of electricity (and – if available – heat) of approximately 200 companies is analyzed and allocated to large consumers and additionally collected in the survey as well. In doing so, information about the temporal distribution of the energy demand can be gained and thus conclusions about the kind of useful energy use can be drawn.

3. **Status Quo Survey:** Existing concepts and literature about energy consumption in the service sector will be analyzed concerning existing benchmarks and types of energy use. Subsequently, the results will be summarized. Additionally, major business chains (e.g. hotel groups, food chains etc.) will be contacted in order to consider relevant energy parameters.

While the basic survey of the annual energy consumption comprises the whole service sector and therefore encompasses about 16 to 18 branches, a deeper analysis will be made for the following usage segments:

• Hotels and B&Bs • pubs and restaurants • food retail • non food retail • offices • health care facilities

Partial Outcomes

Basic Survey

Within the scope of the basic survey which was carried out by Statistik Austria, the authors were capable of harkening back to 4,431 individual data records that could be used for the analysis of the energy use in the service sector. Hence, the targeted aim of more than 2.500 individual data records was exceeded. Considering the voluntary participation in this survey, the response rate of about 36.9 % is assessed as positive.

The survey incorporated enterprises of ÖNACE 2008 departments 45-96 (Code G–S) [3], whereupon it was taken care to assure an evenly distribution over the country.

Four industry-specific questionnaires have been developed, all of which contain a uniform part concerning the annual energy consumption and the corresponding energy costs. Additionally, industry-specific parameters like for instance the useful surfaces (total respectively heated) and the number of beds have been collected. The individual questionnaires are of the size of one DIN A4-page.

The emanation of the questionnaire was initially put into practice in October 2009; the return date was scheduled for the mid of November 2009. In mid-December a reminder was sent out, the return date was specified for the mid of January. About 39 % of the response occurred electronically via e-Quest, the rest (61 %) was sent postally.

With the aid of these 4,431 individual data records an extrapolation was carried out in order to determine the structure of the service sector.

The dominating energy carriers in the service sector are electric energy, natural gas, district heating and fuel oil/gasoil for heating purposes. The energy demand accounts for one third of the total energy demand.

Table 1: energy consumption of service buildings according to energy carriers

	energy consumption	proportion
	TJ	%
pellets / briquettes	863	0.7%
wood chips	1,090	0.9%
Firewood	750	0.6%
other combustibles	70	0.1%
diesel / petrol	1,067	0.9%
heating oil	16,187	12.9%
liquid gas	773	0.6%
natural gas	25,453	20.3%
district heating	30,289	24.2%
electric energy	48,714	38.9%
sum	125,256	100.0%

The consistency of the energy consumption was also determined for single sectors like accommodation sector, retail industry, bureaus, etc.

Figure 2 displays the distribution of the energy demand according to the different sectors.

[3] http://www.statistik.at/KDBWeb/kdb.do?FAM=WZWEIG&&KDBtoken=null

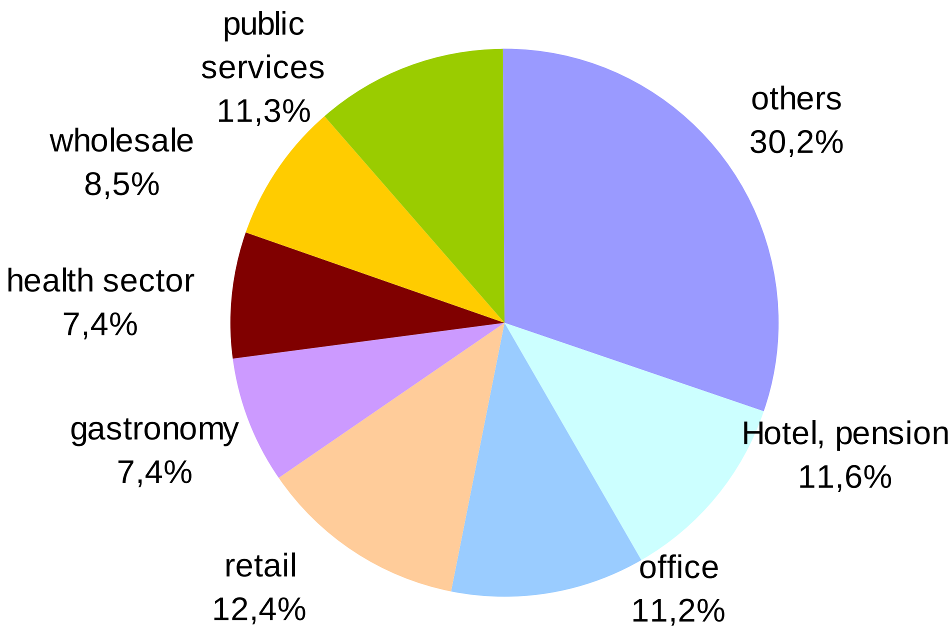


Figure 2: proportion of selected fields of the service sector concerning the energy consumption

Depending on the circumstances, specific characteristic factors have been derived from the analysis in order to analyze the individual sectors.

Figure 3 shows the specific energy consumption for selected sectors of trading and retail. Similar analyses have been carried out for other sectors as well.

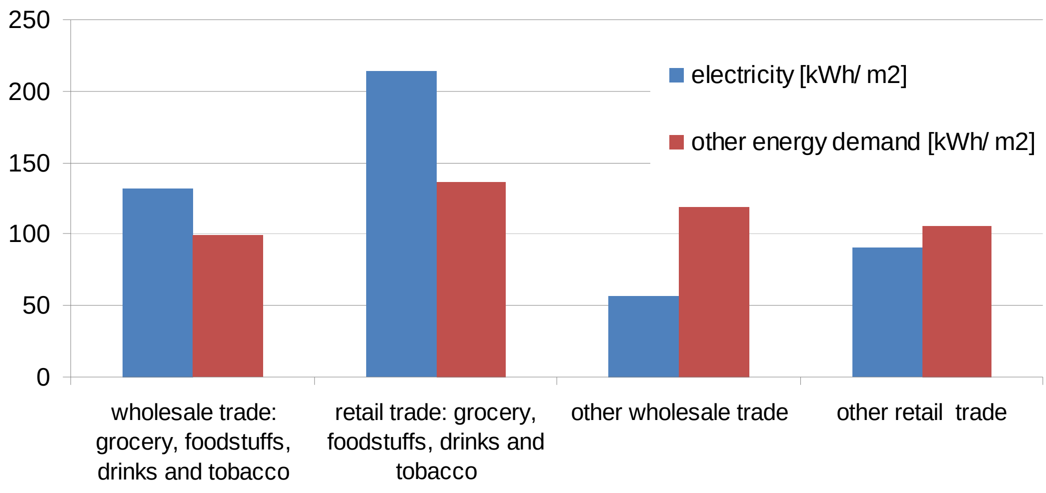


Figure 3: specific energy consumption characteristics for wholesale trade and retail trade

The results of the analysis have been published in a separate report [Statistik 2011].

Status Quo Analysis

Within the scope of the status quo analysis, the already existing benchmarks were identified, whereas it was tried to ensure the actuality of the values. This analysis is supplemented by a comprehensive description of existing literature respectively source citations. As a result, breaking down the sectors into even more detailed scales is considered. The following list shows different kinds of ratios and benchmarks hat can be calculated using the example of food retail:

1. electricity costs/turnover (%)
2. heating costs/turnover (%)
3. electricity demand/employee (MA)
4. thermal input/employee (MA)
5. total energy demand/employee (MA)
6. electricity demand/sales area
7. thermal input/sales area
8. total energy demand/sales area
9. electricity demand/total area
10. thermal input/total area
11. total energy demand/total area

The established benchmarks are published in a separate report [Bayr 2011].

Energy Audits

Within the realm of the SME-initiative for energy efficiency increase which is hosted by the climate funds (“energy efficiency check”), 3,000 energy efficiency surveys have been carried out for Austrian SMEs by the end of 2011. Hence, comprehensive data sets concerning energy consumptions and saving potentials of different branches have been collected.

For the current project, the Energy Institute of the Economy has evaluated data of more than 600 SMEs from the following sectors:

1. food retail
2. hotels *** / ****
3. offices
4. non food retail
5. gastronomy

Each sector is represented by approximately 100 enterprises. Due to this fact and thanks to the quantity of the collected, standardized data, precise conclusions about the energy profile of each branch can be made.

In doing so, all energy carriers that are currently in use are taken into account, which is why the input in heating energy can be evaluated quite well. Moreover, the main consumers / types of use are differentiated according to the following 13 sectors:

1. lighting
2. office equipment
3. electricity customer (without actuators)

4. electric actuators
5. pressurized air systems
6. pumps
7. blowers
8. air conditioning systems
9. heating systems space heating
10. heating systems hot water
11. cooling
12. process heat
13. mobility

The proportion of the principal customers to the total consumption is primarily based on estimated values which are determined by energy consultants specialized on the commercial area; all these data are double-checked regarding their plausibility.

Within the scope of the analysis, the specific values for the particularly important consumer loads for each sector are determined. Taking office buildings as an example, the relevant data contains the required energy in kWh per m² respectively per employee, concerning the five main customer loads (Table 2).

Table 2: The most important energy carriers in office buildings. 50 % of all values are below and above the median. A quarter of the smallest and largest values are below the lower respectively the above the upper quartile.

		lower quartile	median	upper quartile	mean
electricity customer (without actuators)	**kWh/m²**	4	**9**	14	9
Lighting	**kWh/m²**	7	**14**	25	17
air conditioning systems	**kWh/m²**	10	**19**	25	16
office equipment	**kWh/m²**	16	**27**	44	30
heating systems space heating & building substance	**kWh/m²**	75	**102**	137	96

Within the scope of the SME-initiative, the evaluation of the energy audits can contribute informative and complementary data of SMEs, which in turn enables to draw conclusions concerning the proportion of relevant principal customers to the total consumption.

Smart Meter Analysis

Concerning grid-bound energy-carriers, it is common practice to record the energy consumption in an interval of 15 minutes (electricity) respectively hourly (heating). Thus, there are more than 35,000 single electricity consumption observation points available as well as 8,760 heating values. When it comes to smart meter analysis, these values are used. Combined with the time axis, these time series are the linchpin of a building. Interpreting the curve shape facilitates drawing conclusions to the type of use.

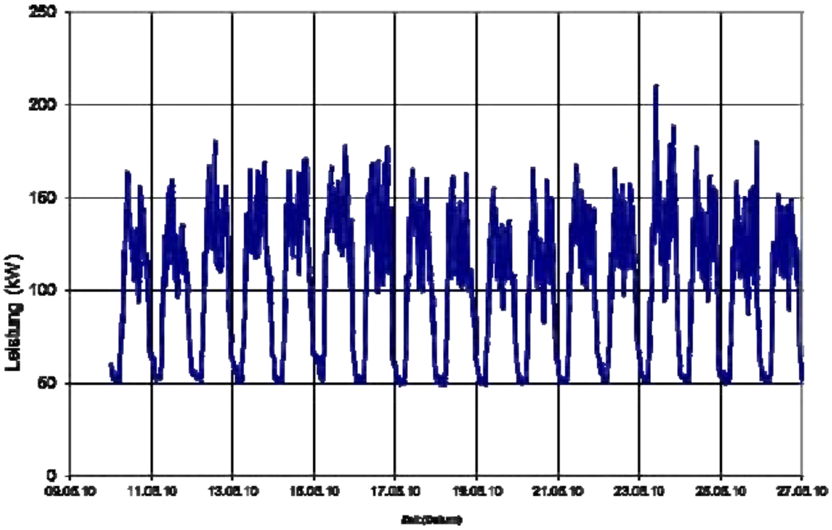


Figure 4: electric load curve of a building

In order to guarantee a standardized analyses of the electriciy power load, a special tool desigend by e7, has been used and was developed further during the analyses of about 200 different kind of power loads.

For the analyse the consumption load is displayed in more than 20 variable perspectives and graphs. The interpretation of these graphs makes conclusions about the type of use and saving potentials possible. New benchmarks, which intrepret the structure of consumption are used. For instance, one benchmark displays the proportion of the annual electricity use outside the utilization time of the building or the proportion of the base load in a standardized way. Moreover, together with the average daily temperature it is possible to see the relation between the temperature and the daily consumption.

Up to now, about 200 energy consumption and load curve analyses were carried out, which is why comprehensive experience concerning operation and interpretation of the tool and its benchmarks could be gained. Furthermore, individual results are to hand.

1. Lighting: with the aid of load curve analysis it was possible to determine the connection load for lighting. By integrating the floor area into the tool, specific electrical supply data for the retail industry could be determined. At the same time, both the specific electric power consumption for lighting (approx. 28 Watt/m^2 in retail shops) as well as the proportion to the total power consumption (> 82 % of the electricity consumption in DIY Market) could be evaluated in individual cases.
2. Base load: the proportion of the base load to the total power consumption (and therefore the 24/7 power consumption) is depicted with the aid of a benchmark. In hospitals, the base load is about 75 to 80 % of the annual power consumption; in retail industry, the proportion of the base load is after all more than 52 %
3. Specific consumption: the specific consumption of the total power consumption [kWh/m^2.a] as well as the electric power of the base load [W/m^2] of all investigated objects are determined by default.
4. T_{4000}: This newly developed benchmark describes the proportion of the annual energy consumption that is consumed outside the hours of operation (defined with 4000 hours). In office buildings, the proportion is about 30 %.

5. Temperature: By integrating the average daily annual temperature into the tool, a dependency of the energy consumption on the temperature can be anlaysed (cf. Figure 5). Moreover, it can be specified at which ambient temperature changes for cooling or heating can be remarked.

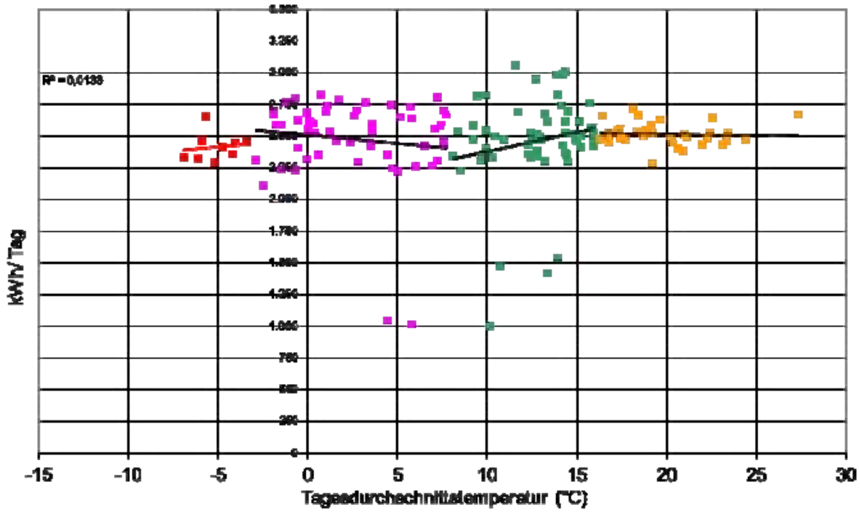


Figure 5: dependency of the electricity consumption on the average daily temperature (example: hospital with district cooling, 2010)

Experience shows that with this tool it is possible to determine a saving potential of about 10 % of the usual total energy demand in a building. These conclusions can be done without even visiting or scrutinizing the building; just by the mere analysis of the load curve. This saving potential is not directly calculated by the tool, but rather is based on interpretation of the load curves' shape. Even better results can be reached if the load curve is analyzed together with the building user.

In the meantime, the tool has shown nexpected dynamics and generated its own considerable momentum beyond the realms of the project. Apart from the building sector, also ski lifts and street tunnels have been analysed among others. Several energy consultants as well as the building administration of an Austrian federal state regularly use the tool. Usually, the tool is used within the scope of an energy consulting before visting the building for the first check. Practice shows that the effort for an initial survey can be reduced considerably.

Generally, the following statements can be proposed about this tool:

1. With the aid of the tool, new approaches concerning energy saving potentials can be developed and pushed forward. Basically the electric power demand outside the peak consumption periods is concerned when it comes to this topic.

2. The tool is perfectly suitable for identifying energy efficiency potentials in a certain market segment which hasn't been paid much attention due to economic reasons. There are numerous SMEs with an electric power consumption of approximately 150.000 to 250.000 kWh/a and hence with electricity costs of 20,000 to 30,000 €/a. Scheduling the payback period with a maximum of three years and given an energy saving of 10 %, only about 5,000 to 10,000 € would be at disposal for the analysis and energy saving investments. By dint of the tool, the implementation time can be shortened significantly and the energy efficiency potentials can be realized quicker.

3. A further development of the tool is carried out continuously

4. Regarding the heat load, a other tool has to programmed, as the analysis of heat curves deviates from an electric load curve analysis. Usuallay the data are valauable per hour and

not per quarter of an hour. The head load wad That is why a different interpretation approach to the curve shape is required.

Next steps

The study about the size and the structure of the consumption of the in service buildings will be finished in June. Within the next few months the results of the case-by-case analyses are merged. The aim is to obtain the assembly of rates of utilization for each sector as precisely as possible.

The final report shall contain an in-depth description of both the composition of the electric power consumption as well as the type of use of service buildings.

The load curve analysis tool is steadily developed further and adapted to new questions and findings.

Literature:

Bayer 2011: Kennzahlen zum Energieverbrauch in Dienstleistungsgebäuden; Österreichische Gesellschaft für Umwelt und Technik; Wien 2011

Statistik 2011: Energieeinsatz im Dienstleistungssektor; Dipl.-Vw. Barbara Mayer; Statistik Austria, Direktion Raumwirtschaft, Energie; Wien 2011

Principles for nearly Zero-Energy Office Buildings

Authors: Bogdan Atanasiu[1], Thomas Boermans[2], Kirsten Engelund Thomsen[3], Markus Offermann[2], Andreas Hermelink[2], Jorgen Rose[3]

[1]Buildings Performance Institute Europe (BPIE), Belgium
[2]Ecofys Germany GmbH, Germany
[3]Danish Building Research Institute (SBi), Denmark

Abstract

The European Union (EU) aims at drastic reductions in domestic greenhouse gas emissions (GHG) by 80% in 2050 compared to 1990 level. By 2050, more than 25% of the stock will be buildings erected from now onwards and for reaching the EU aims, all of these buildings have to be close to climate neutral and zero energy levels. The revised EU Energy Performance of Buildings Directive (EPBD) stipulates that by 2020 all new buildings shall be nearly zero-energy buildings (nZEBs). However, the EPBD doesn't prescribe a uniform approach for implementing nZEBs and calls the EU countries to provide a national definition. Hence, there is an urgent need to establish a set of common principles, aligned to the EU longer term objectives.

This paper, based on a BPIE study launched in November 2011[1], defines and verifies some fundamental nZEB principles as well as provides recommendations for developing a sustainable, effective and flexible nZEB definition for the EU office buildings. The first part of the paper analyses the main technical and policy implications for shaping an effective nZEB definition, taking into account following issues;

- The emission reduction long-term goals,
- Renewable energy disparities,
- The balance between building's energy efficiency and renewable energy supply,
- The influence of climate and building geometry
- And convergence with cost-optimal methodology.

Based on these implications, several nZEB principles are defined. The second part of the paper verifies these nZEB principles on a reference office building, considering different technology options and in three EU climate zones. The results of this reality check are further analysed in the third chapter of the paper, together with the policy impacts for moving towards nZEB office buildings within the EU.

1. Introduction

Throughout Europe there is a large variety of concepts and examples for very highly energy efficient buildings or climate neutral buildings: passive house, zero energy, 3-litre, plus energy, Minergie, Effinergie etc. In addition, these definitions refer to different spheres: site energy, source energy, costs or emissions. Moreover there may be further variations depending on whether new or existing, residential or non-residential buildings included. In essence the views on how nZEB should be defined differ considerably.

Generally, low-energy buildings will typically encompass a high level of insulation, energy efficient windows, high level of air tightness and balanced mechanical ventilation with heat recovery to reduce heating and cooling requirements. In order to achieve a high energy performance level, they will typically take advantage of passive design techniques and active solar technologies (solar collectors for domestic hot water and space heating or PV-panels for generating electricity). In addition other energy/resource saving measures may also be utilized, e.g. on-site windmills to produce electricity or rainwater collecting systems.

At the moment, more than half of the Member States (MS) do not have an officially assumed definition of a low or zero energy building. However, various Member States have already set up long-term strategies and targets for achieving low energy standards for new buildings. A summary of these strategies has being presented in table 12.

The existing low-energy buildings definitions among the EU Member States have common approaches and differences and there is a need to aggregate and improve the existing concepts in order to harmonize them to the nZEB requirements as indicated by the EPBD and also the Renewable Energy Directive. Therefore,

[1] Principles for nearly Zero-Energy Buildings. Paving the way for effective implementation of policy requirements. Buildings Performance Institute Europe (BPIE) 2011, available online at: www.bpie.eu
[2] Based on Erhvervs- og Byggestyrelsen: Kortlagning af strategier for lavenergibyggeri i EU Lande, Februar 2011.

there are three main issues to be considered when the existing low-energy buildings definition should evolve towards a nZEB definition:

1. Most of the European countries that have definitions specify the maximum primary energy per square meter and year as a percentage in relation to the existing national building standard. However, the specific values differ among the methodologies according to what is considered as to be the specific energy demand (from heat demand only, to HVAC, hot water, lighting and electricity or different heated areas).
2. The existing low-energy building definitions do not specifically indicate a certain share of renewables in the energy supply (as requested to happen by 2014 according to the RES Directive). Especially this lack of guidance for the share of renewables makes current regulations or definitions not fit with the nearly zero energy definition from the revised EPBD.
3. There are various elements of existing concepts that can be used for the development of a nZEB definition, such as the principle of working with overarching targets accompanied by "sub-thresholds" on specific issues such as the passive house concept with its requirements on maximum primary energy demand and additional limits for heating energy demand, or/and imposing a threshold for the CO2 emissions.

2. Challenges in setting sustainable nZEB principles

Acknowledging the variety in building culture and climate throughout the EU, the EPBD does not prescribe a uniform approach for implementing nZEB and neither does it describe a calculation methodology for the energy balance. To add more flexibility, EPBD requires Member States to elaborate national definitions and to draw up specifically designed national plans for increasing the number of nZEB by taking into account national, regional or local conditions.

Consequently, it is necessary to provide supplementary guidance to the EU Member States by proposing a set of common principles that secure the sustainability of the national nZEB definitions and plans. Trying to elaborate these common principles, we identified a set of 10 main challenges, presented as questions, which have to be addressed before transposing the EPBD requirement into practice. These challenges are such as in the followings:

1. To what extent do current EU energy and climate targets influence the ambition level of a nZEB definition?
2. How to better define the nZEB for achieving simultaneously the same reduction levels of energy consumption and CO2 emissions of the building?
3. How to deal with time disparities (e.g. monthly vs. annual energy balance) and local disparities (e.g. on-site vs. off-site energy production) in the overall energy balance of the nZEB?
4. How to elaborate the nZEB definition as on open concept that enable the future evolution towards energy-positive3 buildings?
5. When elaborating the nZEB definition, should we be looking at groups or single buildings?
6. Should a nZEB definition go beyond the EPBD requirements by additionally including the household electricity (plug loads) consumption within the scope?
7. Should a nZEB definition go beyond the EPBD requirements by including the energy consumption at construction and disposal phases of the building?
8. How to find an optimal balance between energy efficiency and renewable energy requirements within a nZEB definition?
9. How to elaborate a nZEB definition easy adaptable to different climates, building types and practices?
10. How to link the nZEB definition to cost-optimal levels4 in order to have convergence and continuity between these two requirements of EPBD?

The analysis of these challenges has led to several important implications for the nZEB definition which are presented in the following chapters.

[3] Energy-positive buildings are buildings producing more energy than their energy needs.

[4] As defined in the EPBD, the cost-optimal level means the energy performance level which leads to the lowest cost during the estimated economic lifecycle. The cost-optimal level is defined in Article 2 and described in Article 5 of the EPBD (Directive 2010/31/EU).

Table 1: Planned nZEB initiatives in the European countries

	Existing demand	2010-2011	2012-2013	2014-2015	2016	2020
AT	**final energy** 2010: 66,5 kWh/m2/yr	Proposal 2010: 15% reduction vs. 2007		Proposal 2015: passive house standard for new buildings		
BE	**primary energy** 2010: 136-170 kWh/m2/yr 2011: ~119-136 kWh/m2/yr Variation based on regional demands	2011: ~ 25% reduction in Bruxelles and Wallonie from 2008 and 2010 respectively				
DK	**primary energy** 2010: 52,5-60 kWh/m2/yr	2010: 25% reduction vs 2008 level		2015: 50% reduction vs 2008 level		2015: 50% reduction vs 2008 level
FI	**energy for heating** Regulated through U-values 2011:~65 kWh/m2/yr	2010: 15-30% reduction of U-values. 2011: all new public buildings should be A class	2012: 20% reduction compared to 2010	2015: Demand passive house for public buildings		
FR	**primary energy** Until 2012, by region and heating source: Fossil fuels: 80-130 kWh/m2/yr Electricity: 130-250 kWh/m2/yr		2012: all new buildings at Effinergie standard 50 kWh/m2/yr (primary energy)			**New buildings are energy positive: E+**
DE	**primary energy** 2009: 70 kWh/m2/yr		30% reduction compared to 2009			**Proposal: Climate neutral buildings, zero fossil fuels**
EI	**primary energy** 2010: 100 kWh/m2/yr 2011: 64 kWh/m2/yr	Proposed strategy 2010: 15% reduction vs. 2007	**Proposal: 2013: CO2 neutral Buildings**			
NL	**primary energy** Regulated through EPC factor 2008: ~100-130 kWh/m2/yr	2011: 25% reduction compared to 2008	**2012: climate neutral public buildings**	2015: 50% Reduction compared to 2008		**Proposal: Energy neutral buildings**
PL	**primary energy** 2010: ~75-150 kWh/m2/yr					
SE	**delivered energy** 2009: 110-150 kWh/m2/yr	Proposed strategy: 2011: 20% Reduction compared to 2009		**Proposed strategy: 2015: 25% of new buildings zero energy**		**Proposal for zero energy buildings: 2019: All public 2021: All bdgs.**
UK	**primary energy** Regulated through CO2 demands 2010:~ 100 kWh/m2/yr	2010: 25% Reduction compared to 2006	2013: 44% Reduction compared to 2006		**Proposal: All buildings zero carbon:** 10-14 kgCO2/m2 dependant on dwelling type or Apartments: ~39 kWh/m2/yr Row houses: ~46 kWh/m2/yr, Detached houses: ~46 kWh/m2/yr	
CH	**primary energy** 2011: 60 kWh/m2/yr			2015: Maybe MINERGIE-P: 30 kWh/m2/yr (delivered en.)		
NO	**net heating demand** 2010: 150 kWh/m2/yr			Proposal: Passive house 2014: public bdgs 2015: all bdgs.		**Proposal: Zero energy buildings (delivered en.)**

2.1. Meeting the actual policy requirements and the EU long term climate goals

If EU countries have to meet the 2050 goals for CO_2 emission reduction[5], then the nZEB requirements for new buildings also have to led to nearly zero carbon emissions below 3kgCO2/m²yr[6], which has been assumed to be the average environmental performance of an EU building in 2050. A less ambitious threshold for the CO2 emissions of new buildings may lead to an even higher and unrealistic savings requirement of “90% plus” for the renovation of today’s building stock.

In addition, the recast EPBD stipulates that the EU Member States shall ensure minimum energy performance requirements for buildings ‘with a view to achieving cost-optimal levels’. The EU Commission has to establish a comparative framework cost-optimal methodology which will offer guidance to the EU Member States to further develop the calculations methodologies at national level.

Beyond delivering information for the update of current requirements, the cost-optimal methodology may be seen as the first step in moving towards nZEB levels by 2021. Indeed, the cost-optimal methodology may be

[5] A roadmap for moving to a low carbon economy in 2050, European Commission 2011

[6] Starting from CO2-emissions for the building sector of approximately 1.100 MtCO2 in 1990 (direct and indirect emissions for heating, domestic hot water and cooling) and assuming a useful floor area in 2050 of 38 billion m² in 2050, a 90% decrease of emissions would require an average CO2-emissions of maximum 3 kgCO2/(m²yr).: 1,100MtCO2 x (100%-90%) / 38 billion m² = 2.89 kg/(m²yr).

used, for instance, to calculate the needed financial support (soft loans, subsidies etc.) and market developments (cost reduction for certain technology etc.) and for facilitating a smooth and logical transition from today's energy performance requirements towards nZEB levels in 2021.
Consequently, when determining a threshold for the energy demand for the nZEB, it is recommended to impose a fix value of minimum energy performance (e.g. $30kWh/m^2$ or $50kWh/m^2$) but at the same time to leave some flexibility to this threshold to migrate towards stricter levels within a range which could be defined such as in the follows:

- The upper, least ambitious limit, defined by the energy demand of different building types, would result from applying the cost-optimal levels according to Article 5 of the EPBD recast.
- The lower, most ambitious limit, would be set by the best available technology that is available that is well-established within the market place, e.g. triple glazing for windows.

Therefore, will be easier to define specific country solutions for achieving an overarching target (primary energy/CO_2-emissions), based on the most convenient and affordable balance between minimum requirements for energy demand and for renewable energy share that will supply this demand.
At the moment, in most EU Member States there may be a gap to be bridged between cost-optimal levels and nZEB levels by 2020, while few other Member States will naturally reach the convergence between cost-optimal and nZEB levels, mainly due to the estimated increase in energy prices[7] and expected decrease in technology costs[8].

2.2. Ensuring the convergence between nearly zero CO2 and nearly zero energy buildings

As it was specified earlier, the relation between "nearly Zero-Energy Buildings" and "nearly zero CO2 emission buildings" is important. The aim of the EPBD is clearly to also achieve (nearly) zero CO2 emissions through reductions in energy use. Therefore it is important to establish how a move towards "nearly zero-energy" will simultaneously contribute to a proportional reduction of CO2 emissions[9]. Consequently, it is necessary to elaborate a consistent definition, which should contribute at the same time to both energy and CO2 emission reductions. Hence, the minimum requirements for the energy performance of the building should use an energy indicator that can properly reflect both energy and CO2 emissions of the building as the reduced energy consumption should lead to a proportional reduction of CO2 emissions.
In general, the primary energy use of a building accurately reflects the depletion of fossil fuels and is sufficiently proportional to CO2 emissions. Proportions are only distorted when nuclear electricity is involved. Nevertheless, if a single indicator is to be adopted, then the energy performance of the building should be indicated in terms of primary energy, as in line with current EPBD. However, to reflect the climate relevance of a building's operation, CO2 emissions should be added as supplementary information.
It should be noted that there are additional requirements for ensuring a match between nZEBs and climate targets. In particular, it is very important that the conversion factors from final to primary energy are based on reality and not influenced by political considerations or by an inaccurate approximation.
Moreover the conversion factors should be adapted continuously to the real situation of the energy system.

2.3. Assessing renewable energy production and building an open nZEB concept

The EPBD asks for using 'to a large extend' nearby or on-site renewable energy generation for supplying the energy needs of the building. Renewable energy is on one hand generated randomly (e.g. when is enough solar resource) and on the other hand is not always available onsite or nearby. Therefore, the nZEB definition should be able to properly deal with local and temporal disparities of renewable energy production. This is necessary in order to maximise the renewable energy share and the emission reductions and to ensure a sustainable development of the local heating and cooling systems. Consequently the nZEB definition should consider the following:

- As to local disparities, the most obvious and practical solution is to accept and count all on-site, nearby and off-site production from renewable energy sources when calculating the primary energy use of the building. Allowing for only on-site and nearby renewable energy production could be a considerable barrier in implementing nZEB. Thus the nZEB definition should be flexible and adaptable to local conditions and urban development strategies and it is recommended to allow the off-site 'green' energy production. Moreover, by accepting the off-site renewable energy generation it will enable to transition towards energy-positive building. However, the off-site renewable energy has to be properly controlled and certified for avoiding fraud and double counting.
- Temporal disparities of nearby and on-site renewable energy supply may influence the associated CO2 emissions of the building when off-site energy is used to compensate for periods with a lower renewable energy supply than the building's needs. Therefore, calculating the energy balance of the

[7] Including the national energy tax system development as part of the national activities towards more economic solutions.
[8] Due to volume effects induced by the introduction of the nZEB requirement.
[9] Zero-energy will inadvertently result in zero CO2, however the definition of zero is typically not the "ideal and absolute" zero, but instead a zero over a period of time (an annual mean) and a zero that might be a balance of energy production and use.

building on yearly basis may lead to nearly zero-energy consumption, but not necessarily also to nearly zero-CO2 emissions. The practical solution is to accept either monthly or annual balances. However, if annual balances are allowed, it will be necessary to introduce an additional verification methodology to take into account the associated CO2 emissions of the energy supply over the period. The monthly energy balances are short enough to offer a reasonable guarantee for the emissions associated with the energy supplied to the building. In order to keep the concept as simple as possible it seems reasonable to allow an energy balance on yearly consumption basis, but should leave open the option for a more accurate monthly or at least seasonal assessment.

In order to ensure maximum flexibility and to minimise the risk of lock-in situations the nZEB definition should take into account the following:

- The system boundaries should allow the inclusion of renewable energy from the grid in specific cases when on-site/nearby capacities cannot be installed due to spatial constrictions and/or limitations of local resources.
- The energy balance must take into account the quality of the energy and include a separate assessment for electricity and heating. The quality of the energy production is an important condition for avoiding a misleading nZEB concept with ineffective or counter-productive achievements.

2.4. Finding the proper balance between energy efficiency and renewable energy

For having a proper nZEB definition it is vital to identify the right balance between efficiency measures for reducing the energy demand of the building and the necessary amount of renewable energy for 'greening' the energy supply.

At the moment there are varied approaches, some more extreme than others, each one with pros and cons.

On the one hand, renewable energy integration aiming towards supplying 100% of the energy demand will provide the lowest amount of greenhouse gas emissions, resulting in a theoretical 100% carbon free energy supply. On the other hand, moving towards very low energy buildings by implementing energy efficiency measures may consistently reduce the energy demands of the building sector and may indirectly avoid the construction of new energy capacities or the use of more energy resources, renewable or not. This is a very conservative approach and can be seen as the most sustainable option. However, this case has several constraints:

- Efficiency has its limits and it is not possible to drive energy demand down to zero.
- Energy demand may be very close to zero according to the year's balance but active supply also needs to balance demand peaks over a year (e.g. more heating demand during the winter).
- Consequently a need for the energy supply will still remain, so carbon emissions will still be generated through the use of fossil fuels (indeed, very low emissions).

In conclusion, it appears necessary and also in line with the EPBD's nZEB definition to have a threshold for maximum energy demand as well as a requirement for the minimum percentage of renewables. For this reason, the renewable energy share should take into account only active supply systems such as solar systems, pellet boilers etc. The passive use of renewable energy, e.g. passive solar gains, is an important design element of nZEB, but it seems logical - and also in line with EPBD-related CEN standards to take these into account for the reduction of gross energy needs.

A threshold for energy demand could be set for each country in a given range which may be defined top-down at EU level according to the needs imposed by longer term climate targets and climate adjusted at country/regional level, e.g. based on HDD/ CDD.

The minimum share of renewables to cover the remaining nearly zero or very low energy demand of the building might be chosen in the range of 50%-90% in order to be consistent with EU energy and climate targets. There are two more reasons for choosing the above range as compulsory:

- It is in line with the nZEB definition from the EPBD which requires supplying the energy need of a building from renewable sources to a "very significant extent".
- It is likely to satisfy all the potential requirements for achieving the energy and CO2 overarching targets.

The above proposed requirement for the renewable energy share would also contribute to a paradigm change by moving from renewable energy as a minor substitute of a fossil fuels based energy system towards an energy system where renewable energy is dominant and fossil systems exist only to a certain extent, e.g. to secure the supply during peak loads or as a backup source.

Whereas the bandwidth of the necessary share of renewable energy supply can be derived from technical and financial conditions, the exact apportionment to be achieved at EU or country levels is likely to remain subject to further political determination. A possible practical solution is to start with a certain minimum requirement for the renewable energy share as part of the nZEB definition and to stipulate a further gradual increase of the share.

2.5. Dealing with buildings in different climate, geometry and usage conditions

On one hand, a proper nZEB definition should take into account the climate, building geometry and usage conditions as follows:

1. **Climate:** Two options are suggested for taking into account climate conditions in the nZEB definition:
   - o A first option is to calculate the energy requirement for an average European building located in an average European climate on the basis of the EU's 2050 climate target. This average energy requirement may then be corrected and adapted at national/regional level, i.e. by using the relation of national/regional vs. European cooling degree days (CDD) + heating degree days (HDD).
   - o A second option is to calculate and impose a fixed value, being zero or very close to zero, and the same for each country and all over Europe. Such option would be chosen in the event that the first option appears to be too complicated or it will be necessary to have an absolute zero-energy balance for all new European buildings in order to reach the climate targets.
2. **Geometry:** It appears unfair for buildings with an "easy" shape to have to compensate for the unfavourable geometries of other buildings. Hence, for new buildings differences in geometry do not seem to be a striking argument for differences in energy requirements (e.g. in kWh/m^2yr) and the requirements should therefore be independent from geometry. On the other hand, for the existing building stock this might be seen differently and the geometry aspects should be further analysed in order to avoid additional unfair burdening of the building owners.
3. **Usage:** All residential buildings should meet the same requirements as they typically have the same usage patterns. In addition, non-residential buildings with a similar usage pattern as residential buildings may still have the same requirements as residential buildings. The other non-residential buildings should be classified in as few categories as possible (following the main criteria of indoor temperature, internal heat gains, required ventilation etc.) and should have particular energy performance requirements.

2.6. Looking beyond EPBD requirements: building's electricity need and life cycle approach

Revising the EPBD requirements for a nearly Zero-Energy Building definition, it may well be questioned if the EPBD lists all the relevant energy uses that are actually related to the ultimate goal of minimizing building related CO2 emissions. Based on an extensive analysis, the following is proposed:

- According to the EPBD only the energy use of equipment providing some selected "building services" which are heating, cooling, ventilation and lighting is to be considered in an nZEB definition. Nevertheless there is some further building services that should be a part of a future revised nZEB requirement, as for example, lifts and fire protection systems which represent integrated equipment in the building and are not within the scope of the actual nZEB requirement.
- At this point in time, it is not recommended to include electricity for appliances in the nZEB definition, also because it is not in the current scope of the EPBD. However, over time electricity for appliances should be included in a future version of the EPBD, e.g. via a given value per person or m2 (similar to the approach regarding the need for domestic hot water in current regulations) and consequently in the nZEB definition.
- A feasible interim solution for avoiding sub-optimal solutions might be to systemize all energy uses and clearly show the subset of uses currently included in the EPBD. The energy uses outside the scope of the EPBD do not necessarily need to be integrated in the same energy performance indicator, but they might be mentioned using the same unit along with the EPBD indicator in order to get the whole picture.

To achieve a sustainable nZEB definition it may be important to take into account all the energy uses of a building for two main reasons:

- In low-energy buildings, the amount of household electricity needs for plug loads (e.g. appliances, ICTs) and for technical systems of the building reach the same order of magnitude as the energy needs for space heating/cooling and domestic hot water.
- In Europe, on average, electricity consumption represents comparatively high amounts of primary energy consumption and related carbon dioxide emissions. The same goes for energy use in the construction of the building and its supply systems as well as for disposal of the building.

Concerning the second point from above, a life-cycle assessment (LCA) approach for nZEB is definitely far beyond the current intention of the EPBD. However, energy consumption during the construction and disposal phases of a building becomes more proportionally larger as energy consumption reduces throughout the functional occupation phase of a building's lifecyle. Therefore, there are some practical recommendations to be considered for the time being:

- Due to insufficient consistency of results from different LCA tools it may be too early to assign threshold values. Nevertheless in principle it would make sense to include LCA information in the evaluation of a building's energy performance.
- A practical solution would be to estimate the energy need for production and disposal and require an informative mention of this value, in addition to the indicator(s) reflecting the energy performance of the building. However, ths should be considered at a future EPBD revision.

3. Principles for nearly Zero-Energy Buildings

Concentrating the above findings and implications, we elaborated three basic principles and their corollaries for setting up a sustainable and practical nZEB definition. The principles and approaches for implementing them are described below.

Table 2: Principles for nearly zero-energy buildings

1st nZEB Principle: Energy demand/need There should be a clearly defined boundary in the energy flow related to the operation of the building that defines the energy quality of the energy demand with clear guidance on how to assess corresponding values.	**2nd nZEB Principle: Renewable energy share** There should be a clearly defined boundary in the energy flow related to the operation of the building where the share of renewable energy is calculated or measured with clear guidance on how to assess this share.	**3rd nZEB Principle: Primary energy and CO2 emissions** There should be a clearly defined boundary in the energy flow related to the operation of the building where the overarching primary energy demand and CO2 emissions are calculated with clear guidance on how to assess these values.
Implementation approach: This boundary should be the energy need of the building, i.e. the sum of useful heat, cold and electricity needed for space cooling, space heating, domestic hot water and lighting (for non-residential buildings). It should also include the distribution and storage losses within the building. **Addendum:** The electricity consumption of appliances and of the other building technical systems (i.e. lifts, fire security lighting etc.) may also be included as an additional indicative fixed value.	**Implementation approach:** This could be the sum of energy needs and system losses, i.e. the total energy delivered into the building from active supply systems incl. auxiliary energy for pumps, fans etc. The eligible share of renewable energy is all energy produced from renewable sources on site (including the renewable share of heat pumps), nearby and offsite being delivered to the building. Double counting must be avoided.	**Implementation approach:** This is the primary energy demand and CO2 emissions related to the total energy delivered into the building from active supply systems. If more renewable energy should be produced than energy used during a balance period, clear national rules should be available on how to account for the net export.
Corollary of 1st nZEB Principle: Threshold on energy demand/need A threshold for the maximum allowable energy need should be defined.	**Corollary of 2nd nZEB Principle: Threshold on renewable energy share** A threshold for the minimum share of renewable energy demand should be defined.	**Corollary of 3rd nZEB Principle: Threshold on CO2 emissions in primary energy** A threshold for the overarching primary energy demand and CO2 emissions should be defined.
Implementation approach: For the definition of such a threshold, it could be recommended to give the Member States the freedom to move in a certain corridor, which could be defined in the following way: • The upper limit can be defined by the energy demand that develops for different building types from applying the principle of cost optimality according to Article 5 of the EPBD recast. • The lower limit (most ambitious) of the corridor is set by the best available technology that is freely available and well introduced on the market.	**Implementation approach:** The share of energy from renewable sources which is considered to be "very significant" should be increased step-by-step between 2021 and 2050. The starting point should be determined based on best practice, nZEB serving as a benchmark as to what can be achieved at reasonable life-cycle cost. A reasonable corridor seems to be between 50% and 90% (or 100%).	**Implementation approach:** For meeting the EU long term climate targets, the buildings CO2 emissions related to the energy demand is recommended to be below 3 kg CO2/(m2 yr). Introducing an indicator on the CO2 emissions of buildings (linked to the primary energy indicator for the energy demand) is the single way to ensure coherence and consistence between the long-term energy and environmental goals of the EU.

4. Validation of nZEB Principles: Simulation of reference buildings in different climate zones

To verify and evaluate the proposed nZEB principles and implementation approaches, indicative simulations on reference buildings were performed. The main challenge of the simulation was to provide robust insights into the nZEB principles' effect by applying them to a set of reference buildings, sufficiently representative of the wide variety of building types, while considering at the same time the influence of different European climate zones.

Within an extensive BPIE assessment of the European building stock[10], residential buildings turned out to represent around 75% of the EU building stock in terms of floor area, where single family houses account for 64% and multi-storey family buildings for 36%. As to non-residential buildings, 58% are multi-storey buildings consisting of offices and administrative buildings, educational buildings, hospitals and hotels. Hence, this is a clear indication that the most representative European office buildings are multi-storey buildings.
The application of the nZEB principles is simulated by these two representative buildings and takes into consideration the following three locations which correspond to the main European climate zones:

- Copenhagen, (Denmark), cold climate;
- Stuttgart (Germany), moderate climate;
- Madrid (Spain), warm climate.

4.1. Assumptions for the simulation of the nZEB principles on the reference office building

Based on the above a reference building for the verification of the nZEB principles a new multi-storey office building of 1,600 m2 net floor area was selected with the characteristics described in the following table.

Table 3: Main characteristics of the considered reference office building

Building description	Gross area of 1,653 m^2, distributed on 4 floors and an unheated basement. There are two open offices and one central meeting room on each floor. There are 96 working places (24 on each floor).		
Building geometry	External dimensions		25.2 m x 16.4 m
	Gross area		1,653 m^2
	Net floor area		1,600 m^2
	Offices room height		2.8 m (suspended ceiling)
	Meeting room height		2.5 m (with space for the ventilation ducts)
	Storey height		3.6 m
Building components	Southern façade	Exterior wall area	178 m^2
		Window/door area	182 m^2
	Northern façade	Exterior wall area	178 m^2
		Window/door area	182 m^2
	Eastern façade	Exterior wall area	230 m^2
		Window/door area	0 m^2
	Western façade	Exterior wall area	0 m^2*
		Window/door area	0 m^2*
	Total	Exterior wall area	586 m^2
		Window/door area	364 m^2
	The windows are located only at the north and south façade, with an external automatic solar shading (shading factor of 0.20). The building is considered to be attached to another one.		
Heating	Heated by a central supply system and radiators.		
	The set-point temperatures are: minimum 20°C and maximum 26°C between 6am and 8pm (night setback: 18°C)		
Heat recovery	The heat exchanger is bypassed in summer when the internal temperature rises above 23°C.		
Ventilation	Constant air flow from 6am to 8pm. During summer, natural night time ventilation is activated when the internal temperature is above 23°C and below the external temperature. Ventilation rate is 1.2 l/s/m^2 in offices and meeting room. Infiltration is 0.07 l/s/m^2 heated area.		
Internal heat loads (annual averages)	For people		100 W/ workplace
	For equipment (PCs etc.)		150 W/workplace over the day
			1.0 W/m^2 over the night
	The average presence and usage factor during a 9 hour work day is 0.75. For modelling a realistic distribution with less usage in the early morning and late evening hours as well a lunch break at noon is assumed.		
Hot water	Assumed to be very low (about 2 kWh/m^2/yr), using decentralized electrical continuous flow heaters.		
	The horizon angle of the building is assumed to be 27°.		

[10] Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings, Buildings Performance Institute Europe 2011.

For the simulation of nZEB principles on the reference buildings, it was necessary to pre-define the buildings' parameters for each location, i.e. the thermal performance of the building components and efficiency of the building's technical systems such as presented in the following table. The main criteria for establishing these values were to be significantly better than actual minimum local building standards, but equally to exceed the current best available technology and to be close enough to economic feasibility. In other words, the intention was to apply the findings of the study and to place the energy performance of the reference buildings in the interval below the cost-optimal level (as requested by EPBD) but above the level of the best available technology. The technical systems of the reference building were considered such as in table 5.
For calculating the impact of different supply options in the building's overall energy and CO2 balances, we considered the assumptions from Table 6.

Table 4: Main characteristics of the reference multi-storey office building[11]

Building components' characteristics	Copenhagen	Stuttgart	Madrid
U-Windows (average) [W/m²]	0.74	0.81	1.1
SHCG-glazing []	0.51	0.51	0.33
U-Walls (average) [W/m²]	0.17	0.2	0.24
U-Floor [W/m²]	0.28	0.34	0.42
Specific fan power [W/m³]	0.43	0.43	0.43
Temperature efficiency of heat recovery [%]	85	80	80
Lighting offices* [W/m²]	7.5	7.5	7.5
Peak power of heating system [kW]	60	51	47

Table 5: Overview about the considered heating and cooling systems

	Efficiency Heating/Cooling (annual weighted average)	Efficiency Hot water (annual weighted average)
Air Source Heat Pump (SEER)	3.5-4.1[12]	3.6 – 4.3[10]
Brine Source Heat pump (SEER)	4.6- 5.4[10]	3.6 – 4.2[10]
Biomass Boiler	0.9	0.9
Gas Condensing Boiler	1	0.9
District heating	0.95	0.95
(Micro-) CHP Gas	0.63/0.32[13]	0.63/0.32[11]
(Micro-) CHP Biomass	0.63/0.32[11]	0.63/0.32[11]
(Multi-)Split cooling units for residential (COP)	3.5	3.5
Central cooling system for office	5.0	5.0

Table 6: General Assumptions

	Off-site, grid electricity	Off-site, grid 'Green' electricity	Natural gas	Biomass	District heating	On-site electricity[14]
CO_2 factor[15] [kg/kWh]	0.252	0.0	0.202	0.0	0.107	0.0
Renewable share[16] [%]	35	100	0.0	100	54	100
Primary energy factor[14] [-]	2.0	0.0	1.1	0.2	0.61	0.0

The remaining primary energy factors were taken from the actual EPBD calculation methods of Germany.
The local specific energy production of PV systems per kWp in the chosen locations is taken from http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php.

[11] Lighting (2 rows) with attendance and daylight control (aim: 200 lx) plus individual workplace lighting, to be added to the basic demand
[12] Individually calculated, mainly depending on external temperatures, assuming best actually available market products
[13] heating/electricity production
[14] For the purpose of this simulation, photovoltaic (PV) and micro-CHP (CHP=combined heat and power plant) were considered. It is assumed that CHP is driven as an (inefficient) heating boiler, which produces 100% "green" electricity and may be used for compensation for renewable energy, CO_2 emssions and primary energy.
[15] There are great country differences between the CO_2 emission factors for electricity and district heating, according to the fuel mix content in the energy supply. For simplification the EU-27 average was applied. For the CO_2 emission factors of electricity and district heating average values for the years 2011 to 2040 were assumed, taking into account a constant decrease towards -90% by 2050 (according to the power-sector reduction target).
[16] The shares of renewable energy and the primary energy factor for electricity are calculated as "2011 to 2040"- average values, based on the renewable energy projections of the Energy Environment Agency and the ECN for the EU27.

Within the simulated application of nZEB principles on the reference office building in different climate zones, the following parameters were considered and calculated:

- Specific primary energy demand detailed by building services, i.e. heating, domestic hot water (DHW), cooling, solar thermal domestic hot water, losses.
- Different technology options for providing a building's heating, cooling and DHW: air source heat pump, brine source heat pump, biomass boiler, gas condensing boiler, district heating, micro-CHP gas, micro-CHP biomass, multi-split cooling units for residential (COP), central cooling system for offices.
- Final energy demands in several technology assumptions and detailed by building services (i.e. heating, domestic hot water, cooling, ventilation and auxiliary energy).
- The primary energy demand, the renewable energy share and the associated CO2 emissions of the reference buildings were calculated for each climate zone in two situations with or without considering the electricity consumption of appliances and other building equipment outside the scope of the EPBD.
- Renewable energy: In addition to the basic technical system presented above, the simulation considered several supplementary options such as:
  - One on-site photovoltaic (PV) system of 2kWp
  - Additional use of off-site "100%-green electricity", which is assumed to have 100% share of renewable energy and a CO2 emission-factor of 0 kg/kWh as well as a primary energy factor of 1 kWh/kWh.
- Specific CO2 emissions and primary energy: In addition to the above-mentioned assumptions, a 'photovoltaic compensation' was considered to reach a 50% or 90% share of renewables.
- All analysed options assumed a well-sealed and insulated building shell with a highly efficient ventilation system, leading to a very low energy demand.

4.2. Results of nZEB principles simulation in different climate zones

The simulation results of the reference multi-storey office building in moderate climate zones are presented in the following figures. The estimated impact of the simulation is presented in relation to the suggested thresholds for renewable energy and CO2 emissions as they are defined by the nZEB principles and corollaries defined in chapter 3.
As the electricity produced by PV and CHP systems were calculated as a negative contribution, assuming the CO2 emission and primary energy factors of conventional grid electricity, negative values for the CO2 emissions and primary energy for those variants are possible. In case the on-site renewable energy production systems (PV and biogas CHP) produce more energy than the annual demand (=> plus energy buildings based on an annual balance) a share of renewable energy above 100% is possible.

The general findings of simulating the application of the proposed nZEB principles have been summarized in table 8.

Table 8: Impact of different options on renewable energy share and CO2 emissions for the examined office buildings

Renewable energy share between 50% and 90%	CO_2 emissions below 3kgCO_2/m^2yr
• In office buildings, biomass and heat pump solutions reach a 50% share of renewables. • Office buildings have a higher relative share of electricity than residential buildings. Therefore green electricity is very advantageous for all variants – except the fossil-fired variants - to reach a 90% share, usually even including appliances. Due to usual space restrictions, adding PV is less effective.	• All basic variants (excluding additional green electricity and/or PV) except the biomass micro CHP exceed the limit of 3 kg/(m^2yr). • The use of off-site green electricity significantly decreases CO_2 emissions and because of the relatively high share of electricity in office buildings all related variants stay below 3kg/(m^2yr). By including the electricity demand of the appliances does not generally change the result. • Adding PV is not very effective in office buildings. Specific CO_2 emissions below 3 kg/(m^2yr) may be achieved, only without appliances, and by assuming an appropriate amount of additional on-site PV. In some cases (especially fossil heating systems in less sunny places) even this may not be possible.

Figure 1: Simulation results: office building in Stuttgart

4.3. Financial impact of the analysed nZEB options

The financial impact of the considered nZEB options have been calculated by comparing the extra investment costs to achieve the nZEB levels and the potential savings (mostly energy costs) to a local actual new building standard.

The energy prices assumed for the different locations and usage types (residential and office) are shown in table 9. The prices are averages, based on Eurostat data and considering a period of 30 years with an annual price increase rate of 1.5% and an interest rate of 4%. For green electricity for all locations and usage types, additional costs of 0.02 €/kWh are added to the conventional electricity prices. The prices for heat pump electricity and district heat are assumed to be related to the price of gas, assuming the following correlations:

- price heat pump electricity => 2.2 x price of natural gas
- price district heat => 1.24 x price of natural gas

For the reference and the CHP options, with a comparably high demand, have to be assumed different (demand dependent) prices for gas, biomass and district heat than for the nZEB options.

The inputs related to the average assumed investment costs are described in the Table 10. However, the investment costs are dependent on specific market circumstances, contract negotiations, sale volumes and might differ substantially at the level of single projects.

Table 9: Assumed average energy prices for the period 2011-2040 for the services sector

	Copenhagen	Stuttgart	Madrid
Electricity conventional [€/kWh]	0.191	0.199	0.280
Electricity heat pump tariff [€/kWh]	0.106	0.114	0.107
Green electricity [€/kWh]	0.211	0.219	0.300
Natural gas [€/kWh]	0.048	0.052	0.049
Biomass [€/kWh]	0.040	0.043	0.040
District heat [€/kWh]	0.060	0.064	0.060
Natural gas – gas CHP & reference [€/kWh]	0.089	0.066	0.071
Biomass – wood pellets & bio-CHP [€/kWh]	0.073	0.054	0.058
District heat (>20GJ/yr) [€/kWh]	0.111	--	--

Table 10: Additional specific investment costs (Euro2010, incl. VAT)[17]

Additional Investment costs for energy efficiency measures (euro2010, incl. VAT)[18]				
Component	Unit	City/climate zone		
		Madrid	Stuttgart	Copenhagen
Improved windows glazing	€/m² glazing	150	50	0
Improved heat recovery	€/m² floor area	20	25	15
1 cm roof insulation	€/m²	0,69	0,99	1,27
1 cm wall insulation	€/m²	0,91	1,32	1,69
1 cm floor insulation	€/m²	0,86	1,24	1,59
Specific costs for the PV system	€/kWp	3300	3300	3300
Improved lighting	€/m²	2	5	2

Additional Investment costs for heating systems (euro2010/m², incl. VAT)[17]								
	Air heat pump	Brine heat pump	Biomass boiler	Gas boiler	District heating	Micro-CHP gas	Micro-CHP biomass	Gas boiler
Madrid	26,2	41,2	21,2	12,4	7,8	49,8	60,9	17,5
Stuttgart	39,4	62,9	31,7	18,7	11,7	77,3	94,5	37,5
Copenhagen	54,7	90,4	45,0	27,2	17,0	114,7	140,0	24,5

The investment costs identified within the study are in the range of EUR 12,400 - 224,000 for the reference office building. The cheapest option is the district heating; the most expensive option is the biomass micro-CHP.

Based on the above assumptions, figure 2 shown the additional annual costs per net floor area over a period of 30 years, considering an interest rate of 4% (without inflation). For the calculation of the annual costs, the annual energy prices savings (negative) were added to the annual additional investment and potential additional maintenance costs, which are necessary to reach the nZEB options. Positive values indicate that the additional costs are higher than the achievable savings.

The average investment costs for using different heating technologies vary largely according to the local market circumstances, contract negotiations, sales volumes etc. and might differ substantially from one case to another.

The results are very much influenced by the local prices for systems, energy prices and the existence of a certain support scheme (e.g. feed in tariffs). Therefore, without insisting on detailed prices, the outcomes of the financial examination are given in the followings:

- Overall, CHP solutions tend to be the most expensive.
- Especially in southern but also in central Europe, nZEB might be even more financially attractive than the reference case. In northern Europe higher costs can be expected.

[17] Sources: Ecofys BEAM2 model, report "Heating systems: Heating concept for Germany - Environmental impact from heating systems in Germany, for German Umweltbundesamt, 2009/2010", and use of construction costs indicators (EUROSTAT), own investigations.
[18] comparison to the actual new build standards at the location

- Adding PV in northern Europe increases the overall additional cost, in central Europe (Stuttgart), the price difference to a reference case is very small while in southern Europe the more PV is added the more financially attractive the nZEB solution becomes under consideration of the assumed circumstances

Overall, keeping the CO2 emissions below 3kgCO_2/m^{2}yr appear to be affordable in most of the considered options, but especially in the moderate and warm climate zones (figure 3). Within the CO2 proposed threshold, most of the considered options have specific additional capital costs below 3 euro/m^{2}yr. For several considered options the additional costs are even negative which means that the necessary additional investment is lower than the expected cost savings through the anticipated reduction of the building's energy need. Moreover, few options lead to net zero or positive CO2 emissions balance (i.e. the points on the y-axe and the ones having negative values for CO2 emissions in the below graph) with small or even negative specific additional costs.

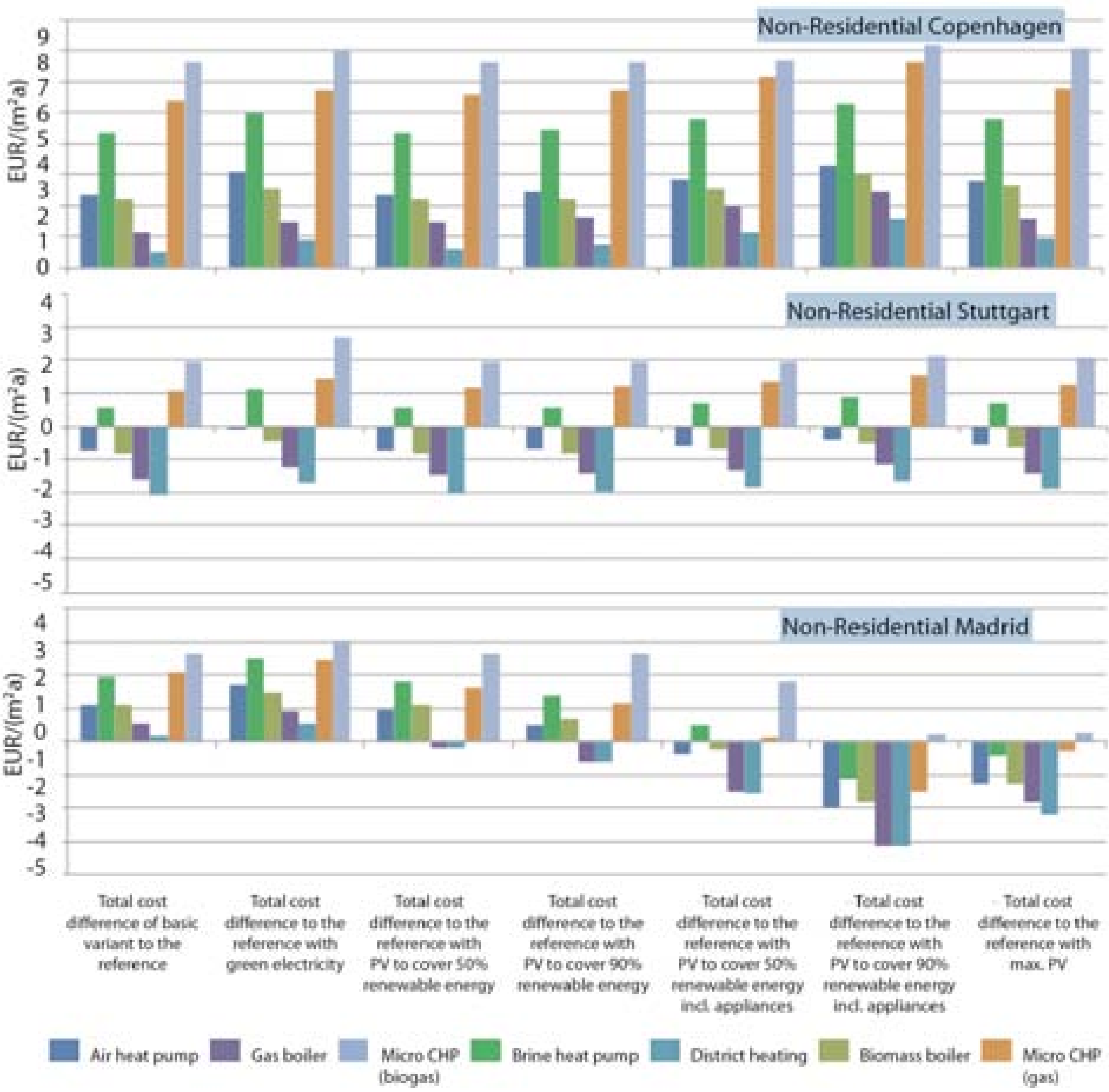


Figure 2: Specific annual costs for the considered nZEB options and climate zones

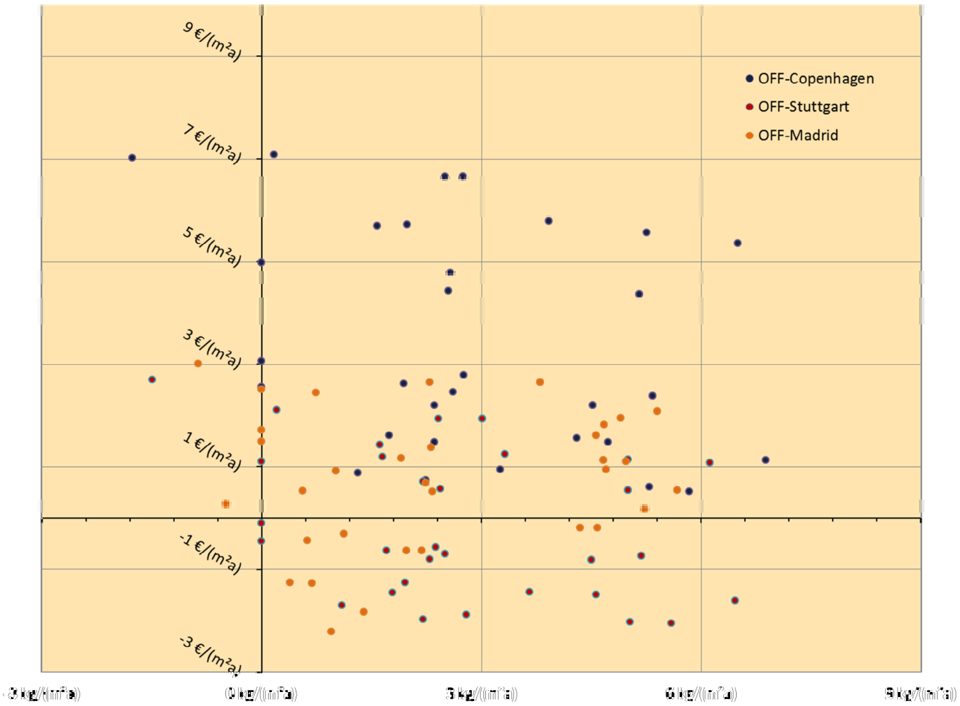


Figure 3: Specific additional capital costs of the examined nZEB solutions related to the actual local building standard (y-Axis) vs. specific CO2-emissions (x-Axis)

5. Final considerations: nZEB implications and steps forward

While a nZEB definition needs to deliver the framework for successful implementation of the related principles at building level, any final nZEB definition needs to and will have technological, financial and policy implications at EU level. The simulations have shown that the proposed nZEB principles are feasible and reachable with already existing technologies. Fossil fuel based technologies are not consistent with the ambition of the proposed nZEB principles.
Further improvements towards highly efficient thermal insulation materials and windows, as well as of heating, cooling and ventilation technologies, and demand control systems will enlarge the available options and will push the nZEB limits towards higher performances and potentially more affordable costs. But for achieving proper levels of market deployment for energy efficiency technologies it is necessary to up-scale the actual levels and to foster the market penetration of promising new technologies.

Apart from market barriers, barriers regarding know-how and number of professionals also exist. To date, 1% of all new buildings in Germany are built according to the passive house standard. Therefore it can be assumed that at EU level the percentage is smaller than 1%. Even considering that nZEB is not necessarily equivalent to a passive house but close to the energy level of passive houses, the factor by which the deployment of nZEBs across Europe should increase can be assumed to be beyond 100. For reaching this market level it is necessary to improve the skills of building professionals, from architects, construction engineers to the trades specialists (installers, electricians, carpenters etc).

A successful implementation of nZEB will also need technology transfer within the EU. This is especially important for technologies to reduce heating and cooling demand. The nZEB definition has to go beyond delivering a method that complies with the EPBD text, so as to fit in with particular targets connected to activities in the building sector, such as those related to energy conservation and to lowering energy consumption, efficient use of resources, climate protection and job creation.

The proposed nZEB principles directly fit with the European Union's energy and climate targets. Moreover, the proposed nZEB principles have the potential to strongly support EU job creation targets by stimulating construction activity as well as innovation and production processes in the supply chain industry. The job creation potential of the building activity can be estimated on the basis of the job intensity in the related sectors, i.e. the turnover potential per employee. According to that calculation, the implementation of nZEB as a mandatory requirement in the future would create about 345,000 additional jobs[19].
The proposed nZEB principles and approaches to implementing them into practical definitions are consistent with the EPBD by assuming the cost-optimality methodology as a transitory instrument converging towards

[19] Assuming an extra investment of EUR 39 billion per year and an average turnover in the EU construction industry of EUR 113,000 (in 2008) per person and year.

the future nZEB requirement. While the simulation of the nZEB principles has been made considering the current situation and market conditions, the future evolution will be crucial for the financial gap between cost-optimality and nZEB requirements.

Depending on the specific context by 2021, the financial gap between cost-optimality and the binding nZEB requirements may need to be bridged by additional policies and support measures. To comply with the proposed nZEB principles, current national codes need to be gradually strengthened towards more ambitious levels, together with a significant increase of the enforcement/compliance and control. Moreover, tightening the existing requirements should happen at the same time with the adaptation of the legal requirements for supporting the market deployment of buildings-related energy efficient and renewable energy technologies.

The effect of local aspects to the energy demand and supply of buildings is considerable, especially in relation to new buildings. For example, before starting the construction of a new building, careful consideration of the positioning and orientation needs to be done in order to maximise or minimize solar gain. The particulars of an urban area, such as its density, are also very important for the energy supply of a building. To further support the implementation of nZEBs, local utilities should play an important role in providing nearby renewable energy – heat, cold and power – to the future nZEBs. An integrated approach between the buildings' and local utilities' policies may facilitate a faster and cheaper implementation of nZEBs. Hence, the smart cities policies should consider and facilitate the introduction of nZEB by providing an energy system well-tailored to the future needs of buildings.
Therefore, the energy optimization of urban structures needs to be part of the sustainability concept for European cities. Sustainable policies in European cities have to contribute to the paradigm shift from a traditional sector-oriented approach to a more integrated approach which ensures the consistency between the district energy supply and urban development.

THE MOVE TOWARD NET ZERO ENERGY BUILDINGS
Experiences and Lessons from Early Adopters
Issue Brief

Anda Ghiran
Research Associate, Institute for Building Efficiency
Armin Mayer
Europe Program Manager, Institute for Building Efficiency

Introduction
Around the world, engineers, architects and policymakers have been exploring ways to deliver highly efficient buildings whose reduced energy demand is satisfied by clean, renewable energy. Building off of the broader concept of a green or sustainable building, the concept of the "net zero building" focuses on the energy dynamics and performance of the building. And as policymakers and leaders align toward the net zero concept, the focus on achieving deep energy efficiency has centered on integrated technologies as well as ways to connect buildings to the natural environment. Lessons learned from early efforts can help to inform the next generation of best practices.

Early projects demonstrate that net zero energy buildings (NZEBs) are feasible and potentially economical even in the shorter term. However in each case, the project developers have faced a number of challenges, invoking some skepticism and uncertainty around the nearly/net zero energy concept. Based on interviews with representatives from over a dozen project implementers,[1] three commonly cited challenges include:
• Processes and transactions costs
• The level of technology awareness
• The engagement of building occupants

This paper considers both the direct and indirect experiences of project developers, key stakeholders and policymakers involved in net zero energy construction and major retrofit activities in commercial and public-sector buildings.

The findings of this research are intended for, among others, commercial and public building managers and decision-makers seeking to optimize cost and resource efficiency (energy, water and waste) as part of long-term building asset management strategies.

Motivations for Creating Net Zero Energy Buildings
One of the most common goals for the individuals undertaking net zero projects was to showcase and demonstrate "the art of the possible" in terms of achieving high energy and sustainability performance in buildings. Among the dozen projects reviewed, the main goal was not to achieve an NZEB per se, but to create highly efficient or near-zero-energy buildings. Most projects were driven by a mix of traditional factors and concerns – long-term cost and resource savings, occupant well-being and environmental responsibility – combined with the desire to illustrate the effect of combining today's technologies and with the right ideas and innovations. Rarely, if ever, was one single factor decisive in driving an NZEB project; in the majority of cases, the communication of an "environmental champion" image was more important than cost savings.

The influence of green trends cannot be underestimated. One project representative claimed that "Everybody is doing it," referring to what may indeed be a broader market transformation toward sustainability in the built environment. Indeed, experiences from the development of green buildings may

[1] Interviews conducted by IBE staff between November 2011-January 2012, names and project information can be found in the Acknowledgements and Appendix A.

be considered a precedent for the evolution of NZEBs. According to the US Green Building Council Global Public LEED Directory, the number of European building projects certified using the LEED rating system has increased dramatically over the past decade.
While studies have begun to quantify the value of 'going green' in terms of higher rent and sale values for energy efficient and LEED buildings,[2] the smaller data set makes it more challenging to quantify the additional value of a net zero building. Respondents clearly noted that they believed net zero could influence the valuation of the space. The sense of a possible market premium did influence project decision-makers.[3]

Challenges to Achieving Net Zero Energy

Several project representatives reported that local (especially municipal) rules and regulations hindered rather than supported their NZEB ambitions. Obtaining the necessary permits, such as fire security approval for wood-based construction, was a particular challenge in several cases.

Some project representatives reported challenges in communicating their NZEB vision to local authorities, and communication challenges also extended to employees and other building users and occupants. Projects seemed to struggle in particular around how to make energy savings visible and around choosing the correct central message to convey. For example, should the motivating slogan revolve around energy savings and environment? Or around occupant health and well-being? Or both?

While the issue of economic value is discussed more in the next section, significant challenges for several projects included the perception of high cost and disbelief or distrust in the actual savings and energy performance (technology) that could be achieved. The idea that buildings can be more efficient and environmentally friendly, as well as more pleasant for tenants and less costly, is not necessarily widespread.

Another fairly prevalent perception was that the transaction costs involved in integrated design processes and other elements of NZEB projects were too high. This translated into challenges for project leaders, who had to communicate and justify why deploying more time, energy and resources up front was necessary to ensure smooth project delivery overall.

Technical challenges related to the procurement of competent service providers, the appropriate technology choices, and the writing of tendering documents were also identified in some cases.

The next three sections regroup the main findings of our research, focusing on challenges and barriers to translating the nearly/net zero energy concept into reality.

Findings and recommendations

1. Processes and transactions costs: Start early, seek advice and stay engaged

For project developers, it is important to engage in early and integrated planning so as to exploit all possible options during the design phase to reduce energy demand and source energy on site. In particular, local rules and regulations need to be examined and understood during this phase, since failure to obtain the proper permits may cause significant project delays. Available incentives and subsidies, as well as financing options, also need to be considered and examined as a priority early in the process.

Once the project is underway or completed, it is critical to stay closely engaged with both the building and its occupants, and especially to make any adjustments to technologies and systems, as performance may differ from projections.

Policymakers wishing to promote the adoption of NZEBs may want to consider education and awareness measures targeted at local authorities charged with permitting and rules for NZEBs in their jurisdictions,

---

[2] http://www.institutebe.com/Green-Building/multiple-studies-document-green-buildings-add.aspx
[3] A 2010 Deutsche Bank Research publication entitled 'Green Buildings: A Niche Becomes Mainstream' provides interesting insights on this topic: www.rreef.com/research/research_3981.jsp

especially since net zero energy may present an entirely new challenge for many local officials. Local authorities are not the only actors who need to be trained and informed regarding NZEBs; in order to create the optimal market conditions for NZEBs, the knowledge and the competitiveness of existing contractors also must be taken into account. “NZEBs are no longer an unknown process, but finding contractors capable of building this kind of construction on deadline and within a reasonable budget is very hard,” said an architect involved in the construction of a passive office building in Brussels. “The day the market will offer a wide supply of informed and NZEB-trained contractors, automatically the prices for these buildings will go down.”

One of the most distinguishing features of NZEB projects in comparison with more conventional projects is the use of an integrated design process, whereby architects, engineers, contractors, project developers and even building occupants convene early in the project cycle to develop a holistic strategy to reduce costs, better anticipate building use patterns, and exploit synergies in energy saving opportunities.
Some form of integrated design process was common in all projects surveyed, whether in new construction or retrofit. In one case, 10 different players were involved in the process. Surprisingly, all parties characterized the process as ”easy,” since all were interested and keen to see how savings could be achieved through collaboration.

An integrated design process may appear more time-consuming at first sight, especially since planning cycles even for traditional building construction and major retrofits tend to be quite long. However, most of the projects examined took less than two years to complete. This suggests that greater effort at the initial planning stages may reduce overall project time. At a broader, macroeconomic level, it may also suggest that with proper planning, policy support, market conditions, and with political investment regarding highly visible projects, Europe should be able to achieve its 2018/2020 NZEB targets.

The architect involved with the passive office building in Brussels stated, “It’s impossible today to build an energy efficient construction without an integrated design process. We don’t know how to do it alone, but when people share knowledge and know-how, it becomes feasible. This helps us to think out of the box.” Furthermore, Bogdan Atanasiu, Senior Expert in Energy Efficiency at the Buildings Performance Institute Europe advises: “When retrofitting commercial buildings, planning the implementation steps is very important. In order to fit in budget, the retrofit should start as much possible with the measures with the shortest payback period, or with the measures delivering an important amount of savings. Being paid back on a normal business timeframe will create incentives for next steps and will strengthen confidence in moving further.”

That being said, some project representatives did indicate that greater incentives may be needed to stimulate integrated design processes and collaboration at broader market scale, especially since there may be initial mistrust between established professions, notably architects, engineers, contractors and real estate professionals. Public authorities and regulators may also be unfamiliar with a nontraditional approach to building design, construction and retrofit, suggesting that educational and outreach work may be appropriate for those audiences. This issue is also addressed in the next section.

There were also significant discrepancies in how projects were paid for, although the majority seemed to rely on traditional bank or owner financing, with support from local or national subsidies. “When
people plan to create a zero energy building, they think only about the investment cost and don’t look further,” observed the CEO of a net zero energy hotel in Vienna. “To create this kind of construction, you need to be passionate about the project, well informed and courageous. Energy efficiency in buildings is about attitude – the attitude to invest money.”

Further work is necessary to examine financing issues related to NZEB construction and retrofits, although existing research suggests that innovative financing mechanisms for nonresidential NZEB projects are not widespread in markets today. “People need to get convinced to do it because it is new and unusual, and of course it is more expensive to build such a structure,” said the project developer of a major net zero energy retrofit in Belgium. “But more and more people are starting to realize that not only the price that you pay to build a house matters, but also the price of living in a healthy environment.”

The difficult economic climate and the lack of energy efficiency incentives and targets, particularly in Europe, also create delays in development of such instruments.

2. The level of technology awareness: Map available technology and service suppliers
Technology awareness may be challenging, since firms may not have the time or expertise to identify the best suppliers, system integrators and vendors for their NZEB projects. However, it is critical to understand as early as possible what kinds of technologies and systems the market can provide before embarking too far down the path of construction or retrofit, as the choices may have significant consequences on budgets and project timeframes.

Among early technology and design decisions, air tightness, windows, insulation and other building shell attributes were seen as critical in most of the projects. These must be well selected, and the building shell must be well designed, both because of the higher cost of these technologies and because of their impact on energy performance. In parallel, other technologies and systems installed should be intelligent and flexible in order to adjust for occupant use patterns. “NZEB projects are like racecars: Everything needs to be perfect,” said an architect involved in construction of a zero energy primary school in France. “The project developers need to motivate the construction team because they need to go further than normal. It’s a new challenge for humanity: Do more with less.”

The use of natural ventilation in dense, polluted and noisy urban settings may present an important technical challenge. This emerged in only one project, but the issues must be considered, especially in the context of urban sustainability and the connectedness of systems. Interestingly, there seems to be little commonality among projects in terms of labels and standards used. Some projects reported a lack of appropriate labels in the markets, while others used a Passive House standard or an Ecolabel as part of their strategies. Several interviewees expressed a desire for greater clarity and commonality of labels in their markets. An NZEB project developer from Austria observed, “I was never interested in the LEED or other certification because I don’t want to sell my building. People invest a lot of money in order to obtain famous certifications when they want to sell the building.”

3. Engaging building occupants: Creating a common vision and long term value
Creating and communicating a compelling vision around the NZEB building is critical to ensuring buyin from a range of stakeholders, most notably the building’s actual users.

Many interviewees pointed out that communicating the life quality and intangible (i.e., nontechnical and nonfinancial) benefits of the NZEB project is more compelling for occupants. Some experts point out that one reason nontechnical messages may be more compelling is that while people may ”fall in love” with buildings, they may not necessarily have similar emotive responses to energy saving technologies, for example.

Gerry Faubert, former Director of Integrated Design at the HOK architectural firm, recalls that for the Net Zero Court project in St. Louis, Missouri, USA, “The challenges were to define affordability and to really balance how much energy efficiency one can afford to buy up front, versus being able to achieve a zero emissions proposition.”

A careful balancing of costs and benefits is common in any retrofit or new construction project. In the realm of net zero energy, high energy performance, and sustainability in buildings generally, the total cost of ownership is frequently used in reference to a more holistic understanding of value: Shortterm returns on investments must be contrasted with longer-term benefits including energy and resource savings, higher ‘green’ market value, and occupant well-being and productivity.

As discussed in the first section on motivations, most respondents in this study agreed that the economic rationale and value assessment of their projects necessarily extended beyond short-term economic considerations.[4] Tellingly, none of the projects reported a negative impact on occupant well-being or productivity. On the contrary, all projects indicated that while there may have been initial questions or concerns about the project, occupants and users were generally more than satisfied in their NZEBs. "In the old building, people were used to working in small rooms, where they could fix the temperature," said the facility manager of the WWF Headquarters in The Netherlands. "Now, in the new building, they work in an open space where heating and air conditioning are centrally managed.

They were skeptical just because it was a new situation, but now they are proud of the building."
In some cases, the building's NZEB credentials actually produced a noticeable increase in the engagement of occupants around sustainability, meaning occupants became more active in helping the building to achieve its energy performance potential. This carries potentially significant implications for return on investment: If the NZEB inspires occupants to become "green champions," the return on investment should, in principle, increase, since occupant behavior may lead to even greater energy and resource savings than initially projected.

In addition, some of the NZEB projects examined are attracting curious visitors and eco-tourists who want to learn more about such buildings. One project actually hired an extra full-time staffer solely to deal with media and other interested parties. "I didn't realize how important it was to build a zero energy hotel until I did it," said the CEO of the net zero energy hotel in Vienna. "After that, journalists around the world wrote about our story, delegations from different governments asked for guided tours, and the occupancy increased. I believe that everybody thought about me: 'She did it. She proved that it works for hotels, and moreover, she makes business with it.'"

Conclusions

Evidence from project experience shows that NZEBs are feasible, potentially economical even in the shorter term. Project proponents believe that, in general, NZEBs perform at least as well as if not slightly better than conventional buildings.

Cost and performance are not necessarily the main motivating factors for going to net zero energy. Projects seek to demonstrate the benefits of integrated design, long-term economic value, and healthier occupant spaces. The pioneers in net zero have put a range of options on the table.
New decision-makers interested in exploring net zero can be well served by examining the lessons from these pioneers. In pursuing net zero building design, they will also be faced with weighing advantages, such as perceived increased health benefits from daylighting and natural ventilation, with disadvantages, such as more complex design and permitting. Does it make sense – all things considered – to make the move to net zero energy? If the 'cocktail' is right it may, but no single factor, whether sustainability or saving money or other, is likely to be singularly persuasive.

Appendices

Policy Background

A growing number of stakeholders globally – from architects and building engineers to national and international policy makers – are attempting to reduce the energy consumption, operating costs and the environmental footprint of buildings. The latest and perhaps most ambitious of these efforts relates to the achievement of net zero energy buildings (NZEBs).[5]

---

[4] Representatives of high performance buildings queried in a 2010 study by Danfoss also suggested that it is important to educate "all professionals involved in building development on how and why high performance buildings make good business sense – that the long-term payoff more than justifies the initial investment and puts that investment in perspective." (Danfoss, 2010)

[5] The abbreviation NZEBs is used in this text to refer, broadly, to net or nearly zero energy and passive buildings , which are generally considered highly efficient, renewable energy fed buildings that generate as much or even more energy - in the form of heat, electricity, cooling, etc - as they consume. Please also see the Institute for Building Efficiency's 2011 'Roadmap to Net Zero Energy Commercial Buildings', available at: http://www.institutebe.com/Green-Building/A-Roadmap-to-Net-Zero-Energy-Commercial-Buildings.aspx

Policymakers in the European Union (EU) have mandated that all new public buildings achieve nearly zero energy status by 2018, and that all other new buildings achieve the same status by 2020.[6] In the United States, states like California have undertaken a comprehensive stakeholder engagement process with the aim of achieving net zero energy status for commercial facilities by 2030.[7]

Methodology

This zero energy building movement is likely to carry important implications for a range of actors across the building chain, including:

• Commercial and public building owners and operators
• The commercial real estate sector
• Engineers and architects
• Financiers
• Building occupants and users
• Local, national, regional and international policymakers

While this research paper does not seek to address all of the possible issues and implications of going to net zero energy, it provides a first step in assessing the extent of these implications, offering learnings, observations and recommendations that may be applicable and of interest for each of the target groups outlined above.

Institute for Building Efficiency (IBE) researchers engaged in five areas of activity to support this research:

1. Interviews with representatives from existing NZEB projects, notably in Europe
2. Engagement and conversations with a range of stakeholders
3. An IBE expert workshop on Sept. 14, 2011, in Brussels
4. A review of available literature
5. Collaboration with the Johnson Controls Building Efficiency business.

While there are numerous and exciting residential NZEB projects completed or underway, this paper is concerned only with nonresidential cases – commercial and public facilities.

Projects Interviewed for this Study

Representatives from the following NZEB projects were queried: In new construction:

1. Elithis Towers, Dijon, France
2. Plus Energie/Passive Sports Hall, Herrieden, Germany
3. Solvis Factory, Braunschweig, Germany
4. Zero Energy Primary School – Antoine de Saint Exupéry, Pantin, France
5. Nature Park Information House, Zwiesel, Germany
6. Wicona Test Centre, Ulm, Germany (connected to existing building)

8 Institute for Building Efficiency www.InstituteBE.com

7. Aeropolis Office Building, Belgium
8. Environmental Technology Center Sonoma State, Rohnert Park, California, USA
9. Hawaii Gateway Energy Center, Kailua-Kona, Hawaii, USA

In major retrofit:

10. WWF Headquarters, The Netherlands (partial new construction)
11. Boutiquehotel Stadthalle, Vienna, Austria (partial new construction)
12. Solar Company, Heusden-Zolder, Belgium
13. Passive School, Schwanenstadt, Austria

---

[6] Agreed in 2009 and 2010 as part of the negotiations over the EU's revised framework building efficiency law – the Energy Performance of Buildings Directive (EPBD) – the term 'nearly' reflects a political compromise agreed between supporters of net zero energy targets and proponents of a less ambitious target. While the precise definition of nearly zero will be established by individual EU countries over the course of 2012 and beyond, in practice the term means that a small amount of nonrenewable energy use will be permitted in buildings carrying a nearly zero energy distinction. The term is also often used synonymously with 'passive house' or building.

[7] See the Zero Net Energy Action Plan for the Commercial Building Sector at: http://www.engage360.com/index.php?option=com_k2&view=itemfacet&layout=generic&tag=find&task=tag&Itemid=180&lang=en

14. IDeAs Z2 Design Facility, San Jose, California, USA

The IBE also conducted a prior interview and podcast in the United States with a representative of the Net Zero Court Project in St Louis, Missouri. In addition, lessons learned from Johnson Controls work on a range of high-performance building and zero energy projects have informed this report.

Acknowledgements and Reviewers
The authors are grateful for the thoughtful reviews and comments we received throughout the research and production of this study. Started through an IBE workshop on challenges to achieving NZEB in the European Union and a dozen of interviews conducted between November 2011 and January 2012 with representatives of Nearly/Net Zero Energy Building projects, the research process and written report benefited from insights provided by a variety of collaborators and reviewers:
Sabine Leribaux, Architect, Architectes Associés, Belgium
Emmanuelle Patte, Associate Architect, Méandre Atelier, France
Pia Regner, ING + ARCH Partnerschaft, Germany
Oscar Hernandez, Engineer, Elithis groupe, France
Bogdan Atanasiu, Senior Expert in Energy Efficiency, The Buldings Performance
Institute Europe, Belgium
Rocky Rohwedder, Chair of the Department of Environmental Studies and Planning,
Sonoma State University
C hris Minning, Analyst, Strategy, Building Efficiency, Johnson Controls
Steering committee of the international energy efficiency in commercial buildings (IEECB) conference

Literature and Resources

The following are select literature and resources that were directly used and cited in this paper and/or are available to interested readers for further reference and information.

[1] Buildings Performance Institute Europe. Principles for Nearly Zero Energy Buildings, 2011. Available at: http://www.bpie.eu/pub_principles_for_n_zeb.html

[2] Danfoss. Industry Research and Report: High Performance Buildings, 2010. Available at: http://www.danfoss.com/North_America/NewsAndEvents/Archive/Company+News/Danfoss-Publishes-High-Performance-Buildings-Research-Report-that-Explores-Path-to-Net-Zero/CC 51EAFA-F02A-4BFF-8554-592A50EB64D5.html

[3] Design Build Institute of America: http://www.dbia.org/pubs/research/

[4] Deutsche Bank Research. Green Buildings: A Niche Becomes Mainstream, 2010. Available at: www.rreef.com/research/research_3981.jsp

[5] Energy Efficient Buildings Public Private Partnership (E2BA). Multi-Annual Roadmap and Longer Term Strategy. European Union, 2010. Available at: http://www.ectp.org/groupes2/params/ectp/download_files/36D1191v1_EeB_Roadmap.pdf

[6] Engage 360 Net Zero Energy Action Plan and other resources: http://www.buildinggreen.com/auth/article.cfm/2010/9/29/California-Takes-Concrete-Steps-Toward-Net-Zero-Energy-Buildings/

[7] European Commission. Low Energy Buildings in Europe: Current State of Play, Definitions and Best Practice. European Union, 2009. Available at: ec.europa.eu/energy/efficiency/doc/buildings/info_note.pdf

[9] European Council for an Energy Efficient Economy (ECEEE). Nearly Zero Energy Buildings: Achieving the EU 2020 Target. Stockholm, 2011. Available at: www.eceee.org/buildings/Steering-2-zerobldgs.pdf

10] Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA). How to Define Nearly Net Zero Energy Buildings. 2011. Available at: http://www.rehva.eu/?download=_/374/03_kurnitski_rj1103.pdf

[11] Institute for Building Efficiency. Roadmap to Net Zero Energy Commercial Buildings, 2011. Available at: http://www.institutebe.com/Green-Building/A-Roadmap-to-Net-Zero-Energy-Commercial-Buildings.aspx

[12] Intelligent Energy Europe. Nearly Zero Energy Buildings in Europe – Perspectives and Paths to 2020; A Brainstorming Workshop. European Union, 2010. Available at: http://ec.europa.eu/energy/intelligent/events/doc/ContrMeetings/zero_energy_02.02.10_report.pdf

[13] Interactive map of net zero energy projects worldwide: http://batchgeo.com/map/net-zero-energy-buildings

[14] International Energy Agency (IEA), Energy Conservation in Buildings and Community Systems (ECBCS)

[15] Programme, Task 40, Annexe 52 – Towards Net Zero Energy Solar Buildings. See: http://www.ecbcs.org/annexes/annex52.htm

[16] Marszal, Anna Joanna et al. Net Zero Energy Buildings - Calculation Methodologies versus National Building Codes. Available at: http://www.iea-shc.org/publications/downloads/Task40a-Net_Zero_Energy_Buildings_Calculation_Methods_and_Input_Variables.pdf

[17] Institute for Building Efficiency www.InstituteBE.com

The Impact of Stakeholder Decision Criteria on Energy Efficient Retrofits in the Mid-Sized Office Sector

Kevin Otto

Robust Systems and Strategy LLC

Liam Hendricken and Patrick Gurian

Drexel University

Andrew Dasinger and William Sisson

United Technologies Corporation

Abstract

Government agencies and policy makers have been considering and implementing regulations and incentive programs on energy consumption in buildings. These are done in the belief that such policies will improve overall energy efficiency of the building stock. There is some evidence of the efficacy of such policies based on before and after studies; however, such evidence remains unclear, particularly projecting from one market or building type to another. We have studied the impact of policies through a bottom-up approach, where we model the building stock upgrades over time based on agent-based decision simulations. We model how stakeholders make capital improvement selections among various retrofit alternatives. Such selections change under different policies and macro-economic conditions. Our area of focus was the mid-sized office sector in the region of the Greater Philadelphia Innovation Cluster, a U.S. Department of Energy HUB project. Through simulation, we analyzed the effect on the overall building stock energy consumption of various incentive, cost and code programs. Policy changes cause changes to individual decision making on capital improvement projects on buildings in the stock that are up for renovation. We find most effective a combination of whole-building-based performance incentives and code restrictions that prevent refurbishment into the worst performing alternatives, resulting in a projected 46% reduction in energy consumption from 2010 to 2050.

Background

A critical issue in carbon emission reduction in buildings is incorporating the spectrum of capital investment choices that can be made by investors or owners, and the impact on carbon emission of these choices. While the carbon impact is global, the decisions are micro-economic considering available capital, changes in operating expenses, payback. They may further consider changes in non-economic criteria such as image and altruistic motives. Future carbon outcomes can differ greatly depending on how such individual retrofit choices are made (WBCSD 2007, 2009). Unfortunately, most scenario projections ignore the micro-economic decision-making of stakeholders over alternative energy efficiency improvements. Typically, discussions of the impact of various technologies are described if they were 100% adopted. When costs are considered, paybacks are not considered for individual projects. Instead, marginal carbon abatement “cost to society” is the macroeconomic indicator considered when comparing the effectiveness of various measures, as if everyone in the market will carry a share of the cost of projects. While appropriate for macro-economic assessments, this approach will substantially mask the real costs experienced by various capital-expenditure decision-makers and what incentives are necessary to entice or push them into more energy efficient actions.

A key sector is buildings, representing 40% of energy consumption globally. In this paper, we present a system of models developed by the World Business Council for Sustainable Development (WBCSD) Energy Efficiency in Buildings (EEB) project to show how the building stock in a submarket will change over time based on different technologies. The newly adopted technologies are micro-economically preferred for the stock under construction or renovation in any given year, due to different prices and efficiencies (WBCSD 2009, Otto et al. 2010).

We apply this approach here to analyze the mid-sized office sector in the Greater Philadelphia Innovation Cluster (GPIC) region. The GPIC is a United States Department of Energy regional HUB focused on improving energy efficiency in commercial and multi-family residential buildings. The results are used to consider the market and policy conditions necessary to motivate the buildings industry stakeholders to radical transformation through deep energy retrofits achieving 50% savings.

In the next section we discuss related work and scenario projections. We then present our building stock decision making model. We end by presenting projection results for the mid-sized office building submarket under different scenarios, and we can conclude what incentives and programs are effective at motivating transformation of the building stock.

Related Work

The IEA has completed several series of well researched reports on sector carbon emissions, trends, technology opportunities, and projections, including The World Energy Outlook (IEA 2009), which presents current demand trends, and the Energy Technology Perspectives report (IEA 2008), which presents global energy and carbon projections. These works provide the foundation for our work on refined costs for sector stakeholders.

Underlying the IEA projections is the MARKAL/TIMES modeling framework (IEA 2010), used internationally by many groups (Goldstein and Tosato 2008). The United States uses a different but similar modeling framework to project energy demands (EIA 2009). All represent the generation, transmission, conversion and end use of energy. Each of these functions has alternative technologies for which the MARKAL/TIMES model makes economically optimal choices, given macro-economic scenarios such as carbon pricing, etc. All these works represent building efficiency choices as simple savings versus first cost decisions, considering each efficiency improvement as additive. This is sufficient for energy analysis of many sectors, but insufficient for energy analysis within the building sector as it ignores the interactions that exist between choices. We incorporate synergies between efficiency improvement interactions as well as their impact on economic decision making, and further explore interactions of incentives, prices, and building codes.

Other related works include studies of technology adoption rates in the building sector. Zhao et al. (2009) define adoption rates for various residential and commercial building technologies in the Chinese market. The IEA has published cost improvement experience curves for various technologies (2000). The American Council for an Energy Efficient Economy (ACEEE) has published capabilities for different building technologies (2004). These and other technology capability and cost projections were used in our work.

Modeling of Stakeholders' Decisions on the Building Stock

Model Structure

As part of the EEB project, the WBCSD undertook a modeling effort to project what it will take to bring about radical transformation of the building stock, in terms of building sector actor and other stakeholder actions (WBCSD 2009). Key questions included what would be required of the building sector industry, construction, financing, trade organizations and government. To quantify these considerations, a model of how the building stock changes due to micro-economic decisions of building owners and stakeholders was developed which we make use of here. This model is different from a typical energy projection model (e.g., a MARKAL model (IEA 2010)) in two respects – it is concerned only with the building sector end use, and the capital investment decisions are modeled at higher fidelity than simply assuming complete adoption of the technology alternative with shorter payback.

The model developed is a conglomeration of separate submodels, as shown in Figure 1. The analysis operates on a submarket basis, here the mid-sized office sector in the GPIC region. A homogenous set of buildings is needed for the analysis, in terms of provided service levels. To do this, the 2010 building stock of 2,250 commercial buildings was represented with 13 typical buildings, each assigned its representative proportion of the total population. Further, the statistics on the age distribution of equipment from the building stock were matched. Then, each of the 13 building types can adopt improvements (or not) over time as each is up for renovation capital improvement decisions.

The model represents a building as 23 energy-related subsystems and materials, including wall insulation, roof insulation, fenestration selections, lighting systems, daylighting levels, primary heating equipment, primary cooling equipment, thermal distribution systems, ventilation systems, passive thermal measures, renewable generation systems, etc. For each such subsystem, various technology options are defined with energy efficiency and first cost parameters. A building alternative is a selection of one technology option for each of the 23 energy related subsystems, defining a very large space of available building configurations. The year 2010 was chosen as the baseline reference year, and a representative set of buildings was defined in terms of energy related subsystem selections. In the model, each building alternative has a (possibly zero) level of building stock.

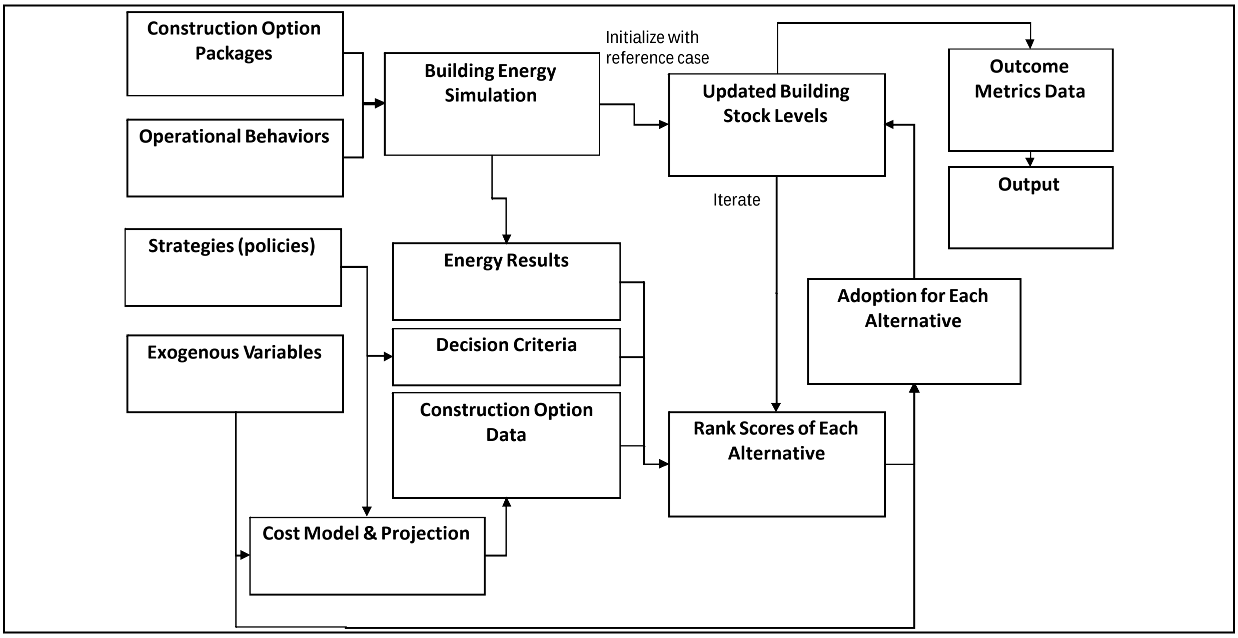


Figure 1: Building Stock Decision Selection and Emssion Projection Model.

Further, each energy-related subsystem has an age, from new to end of useful life. For example, most HVAC equipment has a useful life of 20 years. With this representation, every year a percentage of the building stock in the model is refurbished and decisions over new subsystems selections made. Further, a fraction of the building stock is destroyed and removed from the stock model, and a fraction of new construction also occurs adding again new subsystems and building alternatives into the stock. These three modes of building stock change are used in the model, essentially defining a year-over-year differential equation of the building stock.

The new and refurbished building stock is determined through a rank ordering of alternatives according to the micro-economic decisions of a modeled set of stakeholders. That is, each building alternative is simulated using a whole building energy simulation (e.g. EnergyPlus (DOE 2010)). These results provide the synergistic energy savings of different subsystem technology combinations for a building. The energy savings then provide a payback against the incremental first cost, where we also have a first cost model of materials and installation for each technology alternative. Using these figures, a rank ordering can be defined. This can substantially vary according to macro-economic conditions such as the price of energy, price of carbon, technology learning curves, and also due to government policy incentives or taxes. We further model the impact of building codes by eliminating from consideration alternatives that do not meet different building energy codes at different levels of code.

The micro-economic decision submodel represents several stakeholders who have impact on the capital equipment selection, depending on the decision dynamics of the submarket. We do this through allowing different economic criteria to be the objective function and other decision criteria to be filtering constraints on the selection decision. For example, owner-occupiers might make decisions based on simple economic payback. Owner-tenant buildings, however, do not, since the owner likely pays the first cost whereas the tenant might receive the benefit of lower monthly energy costs. In such arrangements, the linkage between an owner's decision over first costs and perceived benefits are tenuous. In our model, we represent these situations with a multi-stakeholder decision filtering method. That is, we assign one of the stakeholders as the decision maker, such as the owner. They likely have an objective of minimizing first costs. On the other hand, the tenants may prevent this unilateral choice because they will not accept systems with annual costs higher than a certain level. This would define one possible owner-tenant decision model. In our research with stakeholders, we found the typical situation is one where the owner will accept a first cost increment upper bound over the lowest cost alternative, while minimizing the annual operating costs for the tenants. However, this will vary by submarket.

We also built the model to explore non-monetary micro-economic decision factors. We built the model to explore conditions were a decision maker does not use first costs or annual operating cost criteria, but instead makes decisions either wholly or in part by criteria such as impact on indoor environmental quality, operational uptime, or green criteria. One could argue that such criteria can be quantified as an economic value increase, but such value is very difficult to quantify. Therefore, we built the micro-economic rank ordering algorithm to accept any generic utility function, whether economic or non-economic. What is needed is a rating of each alternative on the criteria, and a utility function to combine these ratings into an overall score for each alternative. Generally, we found data on non-economic criteria very difficult to determine for a comprehensive assessment across all energy related subsystems. Nonetheless, we did explore runs where we defined and considered such decisions. The outcome we arrived at, however, was that whatever the decision making criteria, one could always establish an equivalent extended payback period. That is, one could generally describe non-economic decision criteria in an economic fashion through larger payback and first cost limit criteria. Green decision makers look like economic decision makers with extended payback on energy costs.

Whatever the specific microeconomic objective criteria and filtering constraints, the year after year result is a sorted list of the preferred alternative building configurations, independently for new construction and retrofits. Our approach is to then convert this rank ordering into a distribution of building stock alternative increments for that year. If an alternative has high rank ordering, it is assigned a higher percentage of building stock increment that year. Thereby, the building stock alters year after year according to the micro-economic decisions being made. These incremental calculations on the building stock are iteratively made from 2010 to 2050.

With the building stock level projections calculated to 2050, the associated energy consumption and carbon emission projections are also aggregated. This is done for any macro-economic scenario defined, in terms of energy prices, carbon prices, technology learning curves, and government policies such as incentive programs, tax programs, and building energy efficiency codes.

The GPIC Region Mid-Sized Office Sector

The modeling requirements are data intensive. Cost and efficiency curves are needed for each technology alternative on all 23 energy related subsystems. Submarket statistics are needed on stock levels of types and age of insulation, fenestration, heating and cooling equipment, lighting, etc. Building energy consumption levels and construction cost expenditure statistics are also needed. Further, stakeholder decision making criteria must be determined, either by first-hand research, statistical inference, or both for data verification.

For the GPIC region, we made use of the CoStar database of commercial property listings (CoStar 2012). CoStar maintains the property listings for purchasing and leasing transactions, and contains many but not all property characteristics needed. For our energy modeling purposes, we augmented CoStar data with equipment and envelope properties for similar buildings found in the CBECS sample database (EIA 2003). Through this approach, we constructed a dataset of sample buildings representative of the GPIC region office stock, complete with sufficient information to construct EnergyPlus simulations of each sample. The stock considered was mid-sized office, which in the Philadelphia region consists 2-4 story buildings with either brick or concrete-steel façade, 25% or 60% window area, very limited insulation, fluorescent lighting, and either rooftop packaged units or separately zoned unitary systems for heating and cooling.

Policy Impact on Stakeholder Decisions and the Building Stock

Business As Usual

To define a baseline for comparison purposes, the model was run assuming no policies were in place, which we define to be business as usual (BAU) (even though a variety of policies are currently in use within the GPIC Region). The results (Figure 2) indicate that energy consumption is anticipated to fall 12% from 2010 to 2050 without any policy intervention. The primary reason for this result is that as equipment comes up for replacement over time (i.e., reaches the end of its useful life) building owners adopt new ECMs that have the best economic return, which in some cases will also have higher energy efficiencies. Figure 3 plots the EUI versus first cost for all construction option packages, where it is apparent that in 2050 the selected options (green diamonds) all fall on the left-most edge of the possible options (x's). The high energy alternatives are the lowest cost, and generally consist of low efficiency heating and cooling equipment, low efficiency lighting, and poor maintenance. The low cost medium intensity alternatives adopted basically include higher efficiency heating and cooling boilers and air conditions, which become available at the same cost and so get adopted.

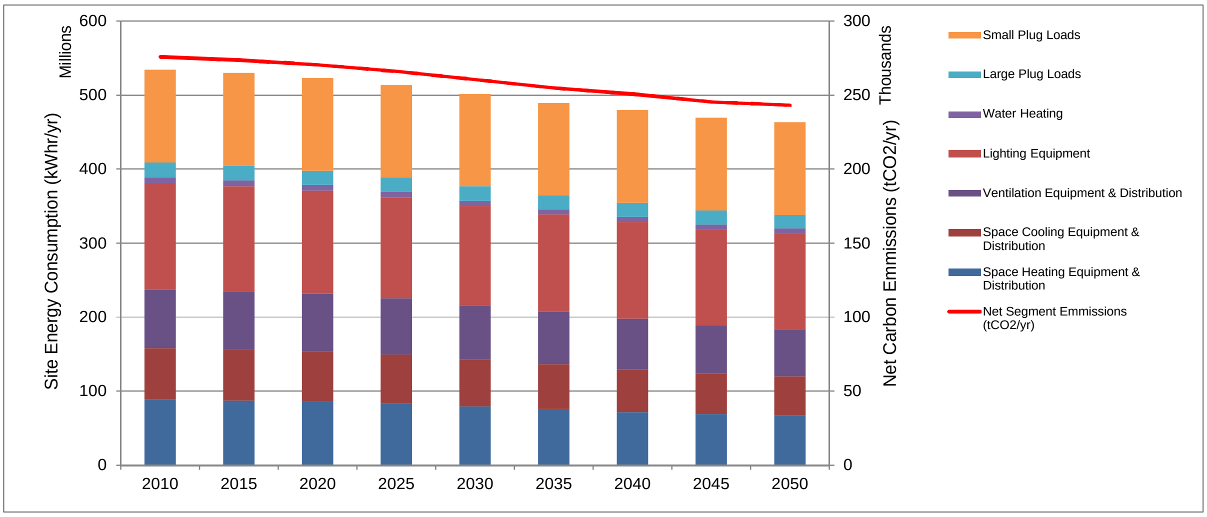


Figure 2: Impact of Current Typical Building Efficiency Policies

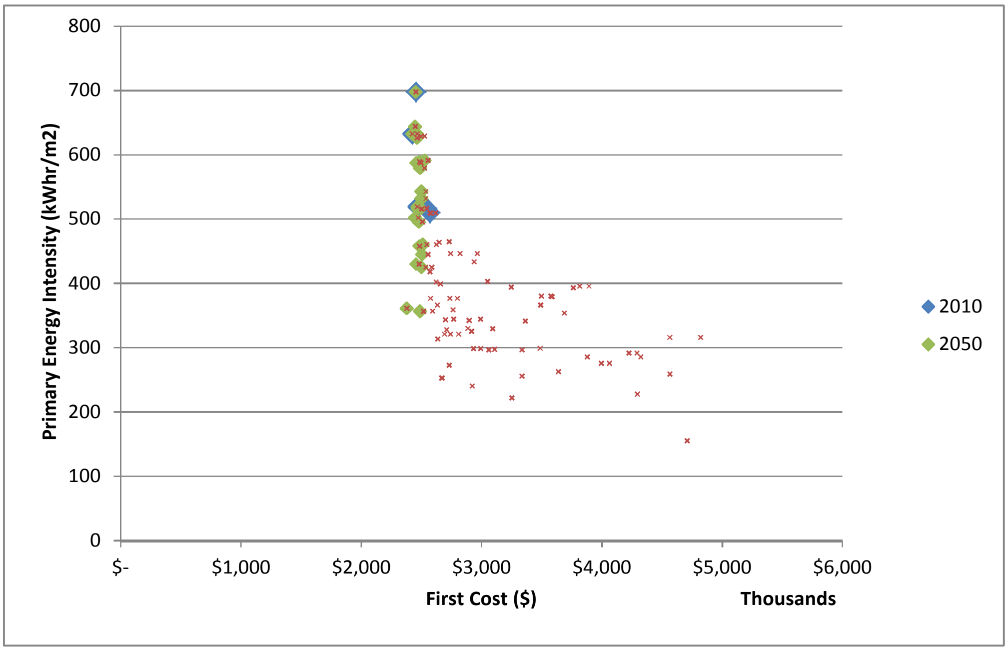


Figure 3. BAU - Current vs. future outcomes based on first cost and energy intensity

Impact of Equipment and Insulation Incentives

Incentives on individual pieces of equipment improve the economics by shortening payback and increasing the rate of return. For example, in the modeled scenario, if a furnace wears out, the price of a high efficiency model to replace it would be decreased 25%, which might be sufficient to induce a higher efficiency replacement. Upgrading individual building systems in isolation produces incremental benefits, but the absence of an integrated approach leaves a lot of savings on the table. As shown in Figure 4, the change in energy consumption over time is nearly identical to the BAU case; by 2050 there is only a 2 percentage point improvement over BAU.

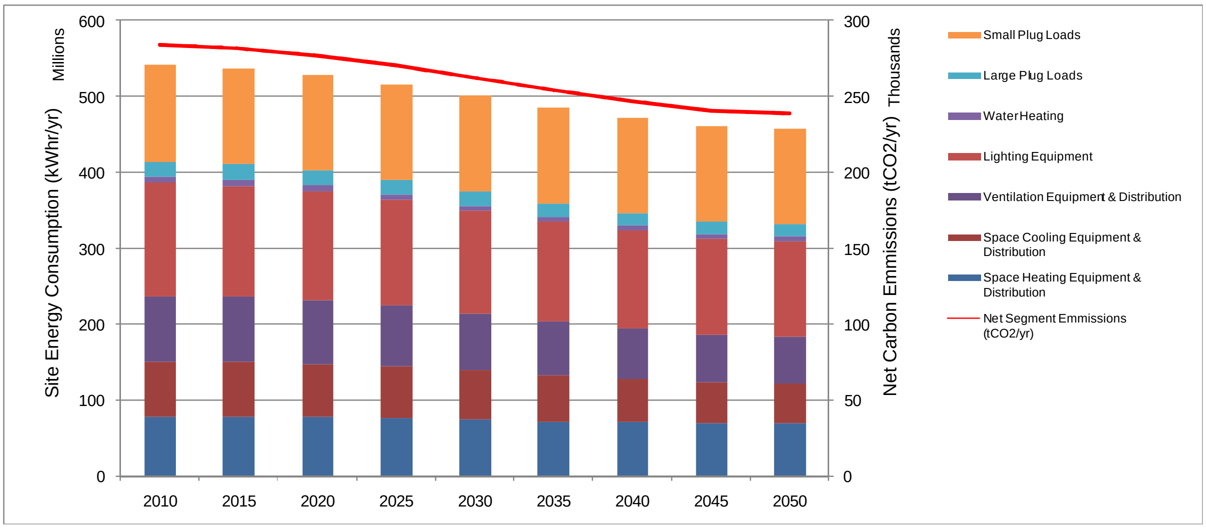


Figure 4. Equipment incentives - projections of site energy consumption

Higher Energy Costs

We tested a hypothesis that substantially higher energy costs – 3 times current prices, for example – would drive building owners toward more efficient equipment. The results of this simulation indicate that increasing energy prices 3-fold does little to stimulate energy efficiency improvements compared to BAU. Figure 5 shows the results for this scenario, which are very similar to BAU (e.g., a slightly more rapid decrease after 2030), while reaching nearly the same end point in 2050.

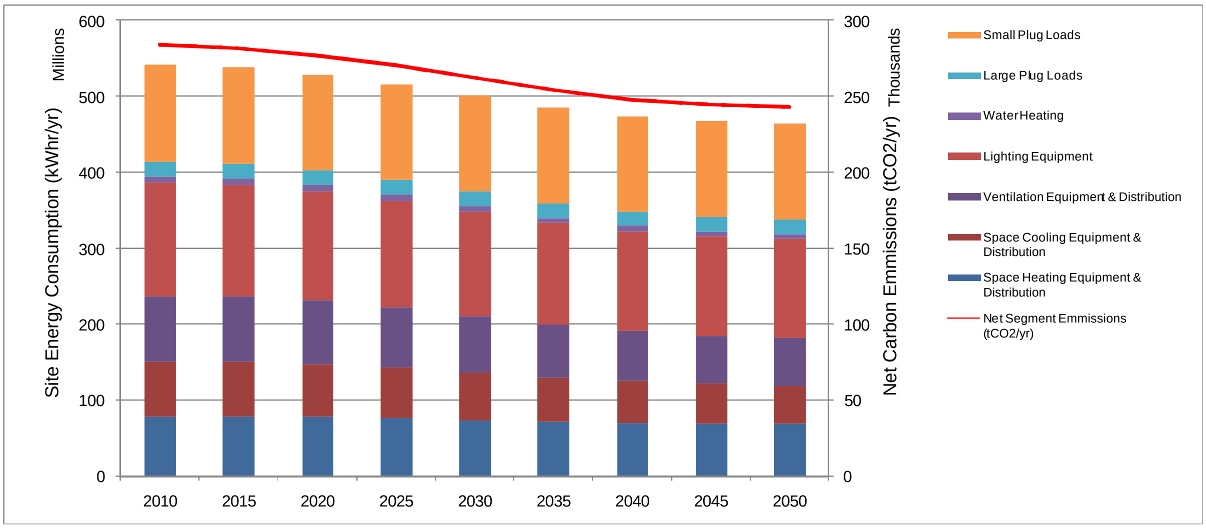


Figure 5. 3X Energy prices - projections of site energy consumption

All Retrofits Must Result in a Building Meeting ASHRAE 90.1-2004

In this scenario we modeled a policy dictating that all retrofit events must result in an entire building upgrade to ASHRAE 90.1-2004 standards. This produces a degree of certainty in a strong result, yielding a 35% reduction in energy consumption by 2050 (Figure 6). This result is illustrated in Figure 7. Notice the buildings adopted by 2050 are the lowest cost options that meet the improvement threshold for EUI, indicated by the horizontal red line.

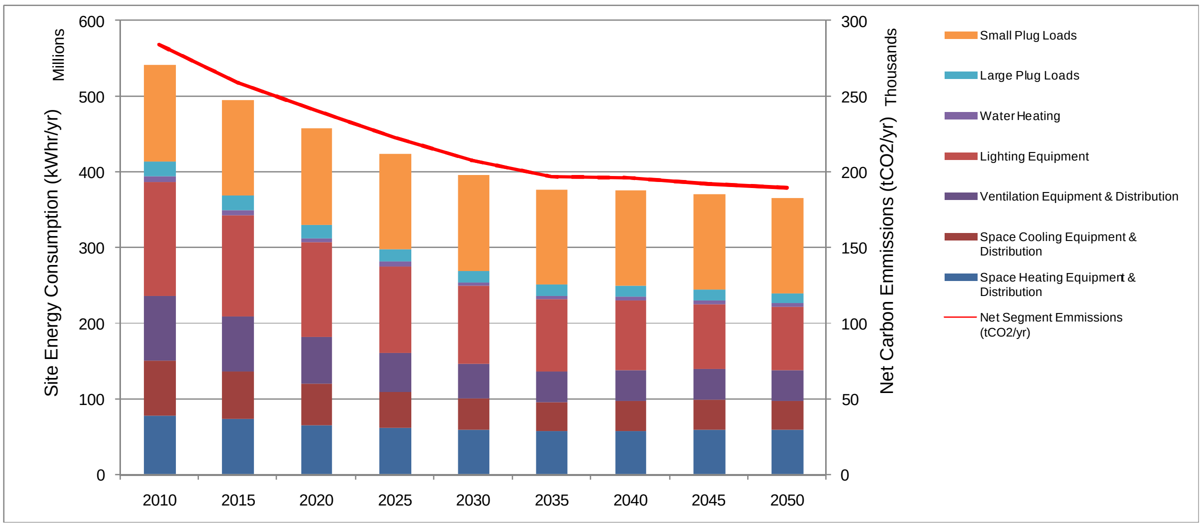


Figure 6. 90.1-2004 Requirement - projections of site energy consumption

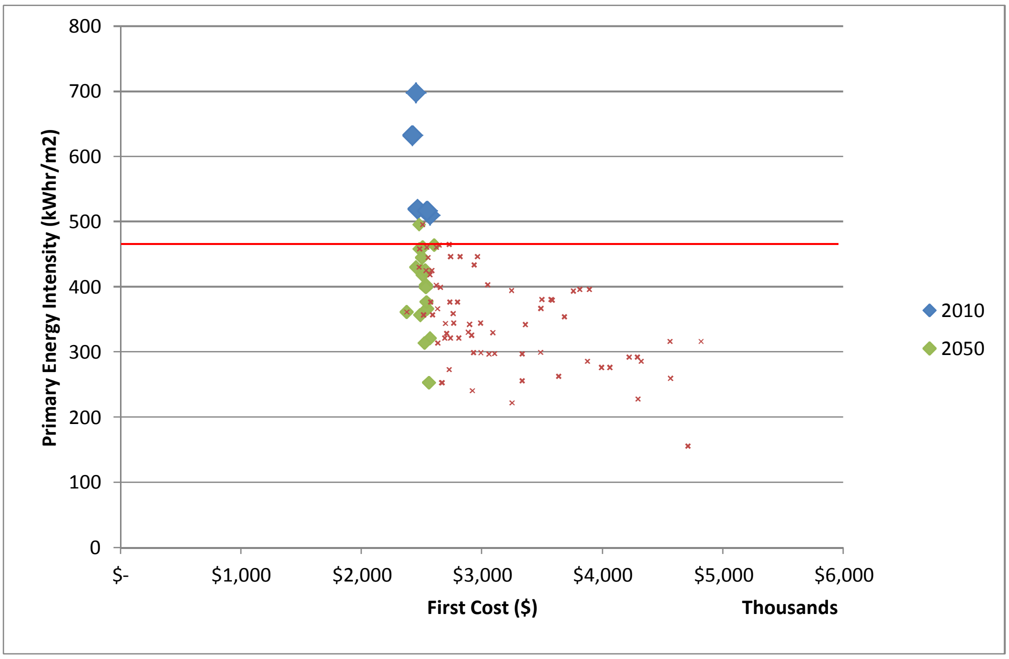


Figure 7. 90.1-2004 Requirement - current vs. future outcomes based on first cost and energy intensity

Incentives for Retrofit Combinations Achieving 30% Improvement over ASHRAE 90.1-2004

Rather than incentivize individual pieces of higher efficiency equipment, we postulated that offering incentives for packages of ECMs (construction option packages) that result in energy consumption below some threshold is a more effective policy approach. We modeled a case with a 25% incentive on packages of ECMs if they produce an EUI 30% better than the EUI for a 90.1-2004 code-compliant building. If this level of improvement is not realized, then no incentive is received. This policy produces a relatively steep drop in energy consumption in the 20 years from 2010 to 2030, with a plateau beyond this, resulting in a 31% reduction by 2050 (Figure 8). Figure 9 shows where the buildings end up in 2050 with respect to EUI and first cost. Notice an interesting feature to the final building stock is that one portion gravitates toward the lowest cost solutions and doesn't achieve significant energy reductions, while another portion shoulders higher costs but reduces EUIs to low levels. There are no significant differences in starting systems, the differences are due to availability of the different but equally attractive "total cost" solutions. One fraction is low first cost with high operating cost, and the other has higher first cost but lower operating costs. When incentives are set to reduce the higher first cost equipment to nearly match the lower first cost, they will get adopted to some portion. The result is a separation in 2050 outcomes, where a fraction of the stock made use of the whole building incentives (lower EUI diamonds) and a fraction of the stock did not make use the whole building incentives (higher EUI diamonds).

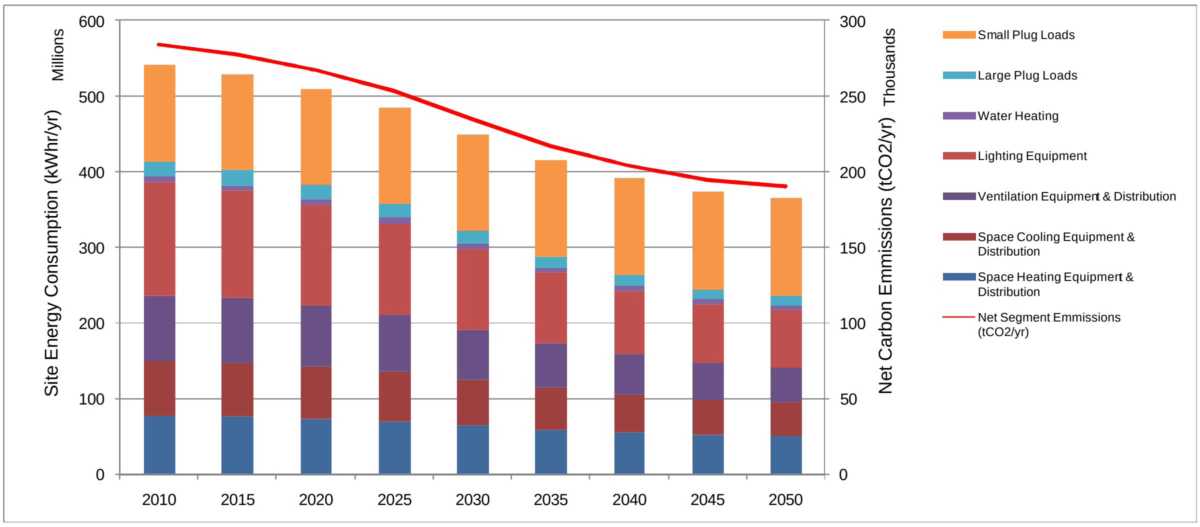


Figure 8. 30% over 90.1-2004 Incentive - projections of site energy consumption

Figure 9. 30% over 90.1-2004 Incentive - current vs. future outcomes based on first cost and energy intensity

Retrofits Trigger ASHRAE 90.1-2004 Requirement, with Incentives for Going Beyond

Combining the previous two policy scenarios produces an end result of a 46% reduction in energy consumption from 2010 to 2050. This carrot-and-stick approach may ultimately be needed to achieve energy reductions on the order of 50%. As shown in Figure 10, essentially all of the building stock has received deep retrofits by 2030, and beyond this no further reductions are seen. Unlike the result for the previous scenario, the buildings by 2030 and beyond are using packages of ECMs that represent the lowest EUI; there is no segment of the population taking the BAU approach (Figure 11). There is a 100% changeover to double-paned windows, a modest shift to 2010 code walls, adoption of white roofs, movement to high efficiency heating and cooling systems, 100% adoption of ducted VAV with economizer, 100% adoption of LED lighting (note that cost curves are used for technologies such as LED in the model), all occupancy sensor lighting controls and all BMS building controls.

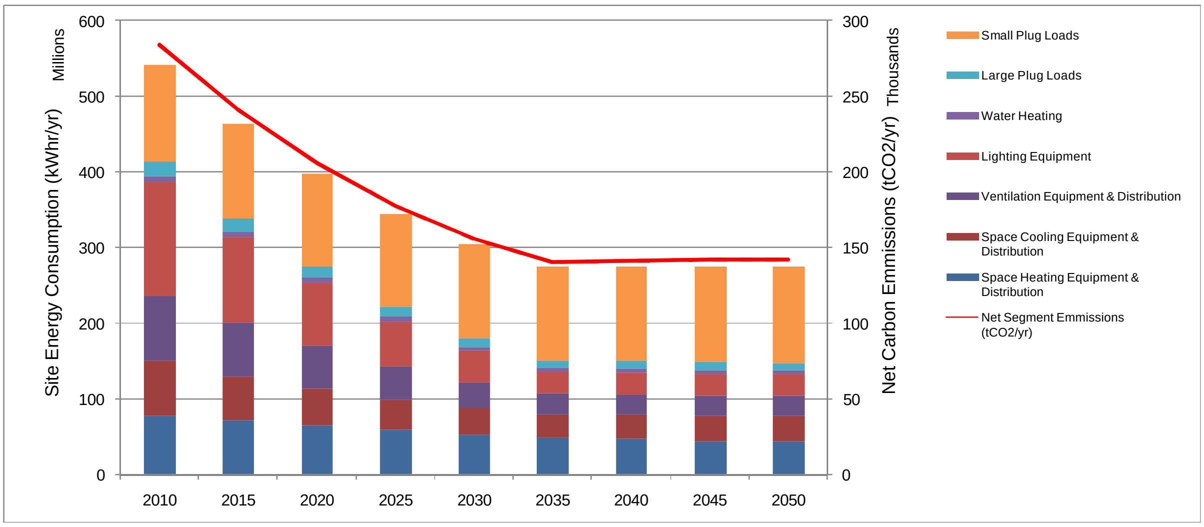


Figure 10. 90.1-2004 + Performance incentives - projections of site energy consumption

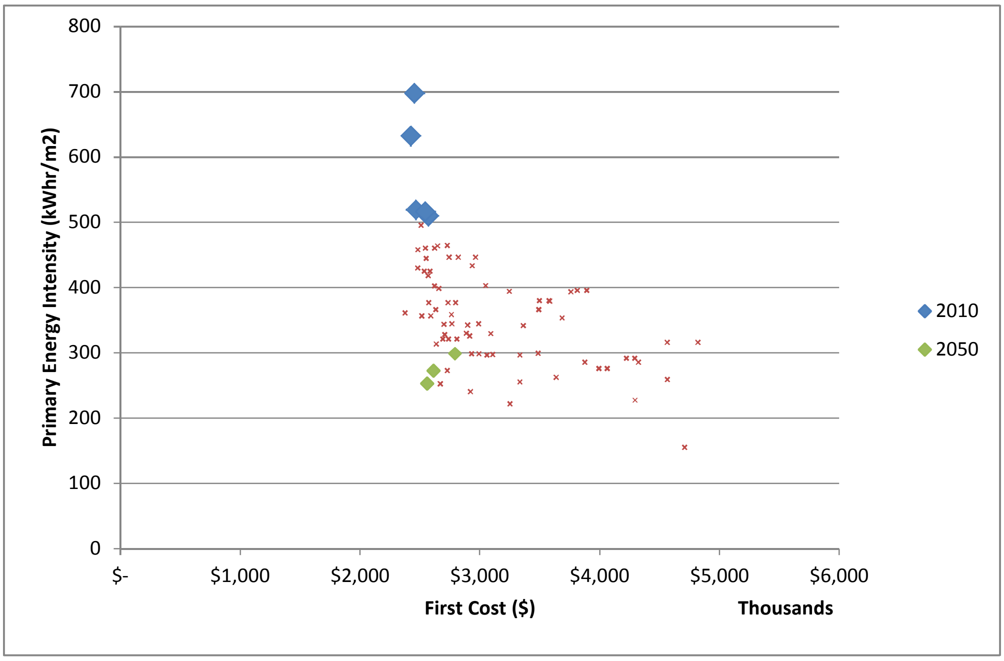


Figure 11. 90.1-2004 + Performance incentives - current vs. future outcomes based on first cost and energy intensity

Summary

The objective of our study was to understand the level of carbon costs or other measures necessary to motivate the buildings industry stakeholders to transform the building energy stock to low energy performance. Most studies assume 100% adoption of a technology and forecast impact. We here extend these works and show the impact of decision making on adoption levels, and particularly how different macro-economic conditions and policy can change decisions and therefore outcomes. Generally, the package of policies that define macro-economic conditions that foster the building sector transformation were not obvious and took some time to generate. On the other hand, it is also clear that neither subsystem incentives nor carbon price alone will impact the building sector, due to low energy costs of a building compared to other costs such as rent or mortgage.

A variety of policy interventions were explored, from reliance on pure market forces to incentive programs, energy codes, and combinations of these policies. The baseline policy scenario of no policy intervention at all and reliance on pure market forces demonstrates a reduction in energy consumption, primarily due to replacement of old heating and cooling equipment with new equipment that has higher efficiency at the same price point. This is shown in Figure 2, where there was no change in stock other than a reduction in heating and cooling energy.

An interesting feature of the buildings market is the very low payback period allowed for investment consideration (typically 3 years) relative to the life of the equipment once a decision is made (typically 20 years). The result is that policies that affect the operating or lifecycle cost are much less effective than those that affect the first cost. This is born out in Figure 5, where increasing energy costs had no impact. Figure 4 also shows this, where incentives on individual equipment had little impact. With incentives offered individually on higher efficiency components, one finds decisions are made to adopt one or two higher efficiency measures such as lighting. However, a complete retrofit of several systems with cost and efficiency synergy (lower energy loads and better insulation create opportunity for smaller heating and cooling systems) are not considered.

We find effective whole building energy codes that require any retrofit to meet a minimum energy performance. This is shown in Figure 6, where high energy efficiency is achieved by all buildings becoming barely under the minimum code. However, while the models bear out a result if the code were adopted, such a policy mechanisms can be difficult to gain approval to be put in place, particularly for buildings with relatively lower revenue generation.

A more interesting result is to consider energy-intensity-based whole-building incentive policies, rather than incentives applied to individual measures. Instead of providing incentives to insulation, high efficiency windows, lighting, heating and cooling equipment individually, the idea here is to instead provide incentives only when the energy intensity of the building is reduced. A key feature is to eliminate the option of only implementing one or two measures, but instead to complete entire synergistic retrofits. Doing so drives lower internal and conditioning loads to the point where it enables smaller, lower-cost heating and cooling equipment. When the level of whole building incentive brings the first cost down to the level of the baseline equipment (generally around 30%), then there is no essential cost premium to the higher efficiency equipment. In this case, either are equally likely, and both are being adopted. This is shown in Figures 8 and 9. To drive only adoption of the high efficiency result, the very low efficiency alternatives must be banned through a code restriction on very low efficiency (very low first cost) alternatives. Then, the medium efficiency alternatives are not selected over the very high efficiency alternatives that are more economical with a whole-building incentive policy. This is shown in Figure 10. We therefore find that both incentives and codes are necessary, properly structured, and can then have substantial impact.

Acknowledgment

This material is based upon work supported by the Greater Philadelphia Innovation Cluster (GPIC) for Energy Efficient Buildings an energy innovation HUB sponsored by the Department of Energy Under Award Number DE-EE0004261.

Disclaimer

References

CoStar Group, 2012, *Property Database*, http://www.costar.com/

Goldstein, G. and G. Tosato, eds., *ETSAP Final Report of Annex X, Global Energy Systems and Common Analyses*, International Energy Agency, 2008.

International Energy Agency, 2000. *Experience Curves for Energy Technology Policy*, Paris.

International Energy Agency, 2008. *Energy Technology Perspectives 2008*, Paris.

International Energy Agency, 2009. *World Energy Outlook 2009*, Paris.

International Energy Agency 2010. *Energy Technology Systems Analysis Programme, Annex VIII: Exploring Energy Technology Perspectives, MARKAL*, http://www.etsap.org/markal/main.html.

International Panel on Climate Change, *IPCC Fourth Assessment Report: Climate Change 2007 (AR4)*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Saches etl al, 2004. *Emerging Energy Saving Technologies and Practices for the Buildings Sector as of 2004*. ACEEE.

United States Department of Energy, 2010. *EnergyPlus Energy Simulation Software*, http://apps1.eere.energy.gov/buildings/energyplus/

United States Energy Information Agency, 2003, *Commercial Buildings Energy Consumption Survey*, http://www.eia.gov/emeu/cbecs/

United States Energy Information Agency, 2009. *The National Energy Modeling System: An Overview*, http://www.eia.doe.gov/oiaf/aeo/overview/

The World Business Council for Sustainable Development, 2007. *Energy Efficiency in Buildings: Fact and Trends Report*. Geneva.

The World Business Council for Sustainable Development, 2009. *Energy Efficiency in Buildings: Transforming the Market*. Geneva.

Zhao. N., McNeil, M. and M. Levine, 2009. *Energy for 500 million Homes: Drivers and Outlook for Residential Energy Consumption in China*. Report LBNL 2147-E, Lawrence Berkeley National Laboratory.

PRESENTATION OF
ENERGY EFFICIENCY AND RENEWABLE SOURCES FUND (EERSF)

Pierre Langlois, President Econoler
Dimitar Doukov, Executive director Energy Efficiency and Renewable Sources Fund

Abstract

The Energy Efficiency and Renewable Sources Fund (EERSF) in Bulgaria was established by the World Bank as a revolving energy efficiency (EE) facility with technical and financial evaluation capabilities. For the period 2005-2010 the Fund's name was Fund "Energy Efficiency" in Bulgaria. The Fund is profit-oriented and will pursue financial sustainability of its own operation. The income from interest fees charged to the fund's clients need to cover the operating costs and losses from defaults. The Fund's objective was to provide support for the increase of EE investments in Bulgaria. The project also aimed to complement existing lending facilities of local commercial banks, not compete with them and in this way to develop EE market in Bulgaria.

The underlying principle of Energy Efficiency and Renewable Sources Fund operations is a public-private partnership ("PPP"). This means that the Fund will pursue an agenda fully supported by the Government of Bulgaria, but it is structured as an independent legal entity, separate from any governmental agency or institution. After five years of operation, the IBRD assessed the Fund's performance and found that the environment in which EERSF operated was very dynamic. Despite competition, EERSF managed to stay one step ahead of the commercial banks and developed innovative financing products, including portfolio guarantees for ESCOs, EE loans and partial credit guarantees, backed by specialized credit risk insurance by the Bulgarian Export Insurance Agency.

The proposed presentation will present the experience gained by the EERSF for the last 6 years* and how such an approach could be successful in addressing many of the financing barriers related to EE projects in the public and the corporate sectors in other countries.

Establishment of the Fund

The decision to create EERSF is supported by the Bulgarian legislation through the Energy Efficiency Act, adopted by the Parliament in February 2004. EERSF is established and initially capitalized entirely through grants - the main donors being the IBRD (World Bank), the Government of Austria, Bulgarian Government and private Bulgarian enterprises.

The main objective of establishing EERSF is to facilitate energy efficiency ("EE") investments and promote the development of an EE market in Bulgaria. To this end, EERSF supports the identification, development, and financing of viable EE projects, predominantly implemented by Bulgarian private enterprises and municipalities. These projects shall result in substantial reduction of greenhouse gases ("GHGs"), which is the main environmental objective of EERSF as a donor project. The new Energy from Renewable Sources Act from 2011 added new function to the fund: financing RES projects, changing its name to Energy Efficiency and Renewable Sources Fund (EERSF).

The Fund is managed by a Fund Manager - a consortium of private companies selected through a World Bank tender procedure. The EERSF operational and finance management is performed by the Fund Manager and the strategic decisions on EERSF's development are taken by a Management Board which is composed of representatives of EERSF's donors and Bulgarian government institution representatives.

The strategic mission of EERSF, defined in the agreement with the donors is development of the local EE market. The task of the Fund during the initial period was to identify a specific own market niche for the energy efficiency credits. Such niche was found in the credit demand of municipalities, small and medium-sized enterprises, hospitals and universities. It was not an easy task, as there were already two successfully operating EBRD credit lines in Bulgaria – a credit line for EE and RES projects in industry and a credit line for energy efficiency in households.

The primary task of EERSF was to be a flexible institution, which takes due account of the changes in the market environment and amends its strategy in accordance with the changing conditions. During the last six years EERSF has played a significant role for the attained changes on the financial products market for energy efficiency projects. A large number of financial institutions developed interest in financing such projects (for which the role of EERSF is not to be underestimated).

The credit activity of EERSF dates back to 2006.

ESCO contracts are becoming ever more popular among contractors and end-beneficiaries. EERSF is the only financial institution in Bulgaria that finances emerging ESCO companies, thereby contributing the development of energy services that have difficulties in obtaining financing from banks, even in developed countries, due to limited ability to provide adequate collateral for loans.

Six years after the start of EERSF operation in Bulgaria there is a real market for financial tools for the energy efficiency domain, which in fact was the primary objective for the creation of the Fund. Being a project of the Global Environmental Facility, EERSF has as its major goal dismantling of the barriers, obstructing the access to funding energy efficiency projects. The Fund Manager, being the Consortium EEE, is fully aware what has been achieved to date is only the foundation for future development of the energy efficiency market in the country.

Legal framework

The Energy Efficiency Act from November 2008 has retained almost unchanged the legal framework of EERSF, created with the Energy Efficiency Act from 2004. The Energy from Renewable Sources Act from 2011 implemented new functions in the field of renewable energy projects financing. The Fund operates according to the provisions of the Energy Efficiency Act, the Energy from Renewable Sources Act and the agreements with the Donors, and is not part of the consolidated state budget. The Fund is a legal entity and manages the financial means allocated for energy efficiency investment projects in compliance with the National Energy Strategy. The Fund follows rules and procedures of operation designed by the World Bank, fully approved by the Bulgarian Government.

Principles of activity

In conducting its activity, the Fund is governed by the following principles:

- Independence;
- Self-funding;
- Profit-oriented commercial operation;
- Transparency in administration of financial resources;
- Partnership with the private sector;
- Equal treatment of all applicants for funding;
- Substantial greenhouse gas reduction through energy savings.

Capitalization

The initial capitalization of EERSF was entirely with grant funds, the major donors being: The Global Environment Facility (GEF) through the International Bank for Reconstruction and Development (World Bank) – USD 10 million, the Government of Austria – EUR 1.5 million, the Government of Bulgaria – EUR 1.5 million, and several private Bulgarian companies. The EERSF has the combined capacity of a lending institution and credit guarantee facility.

Governance structure

The governance structure of the EERSF is provided by Chapter 5 of the Energy Efficiency Act and is amended by the Energy from Renewable Sources Act from 2011.

Governing bodies:

1. **Donors assembly** - adopts the Rules governing its functions and appoints part of the Management Board members (those who are not statutory appointed by virtue of the EEA). Each BGN 1 000 donated confer 1 voting right in the Assembly.

2. **Management Board -** consists of nine members:

- A representative of the Ministry of Economy, Energy and Tourism, designated by the Minister of Economy, Energy and Tourism, acting as the MB Chairman;
- A representative of the Ministry of Regional Development and Public Works, designated by the Minister of RDPW;
- A representative of the Ministry of Environment and Waters, designated by the MOEW;
- The Executive Director of the Agency for Sustainable Energy Efficiency (ESEE);
- Five representatives elected by the General Meeting of Donors of the Energy Efficiency and Renewable Sources Fund, as follows:
  - a representative of non-government organizations, the activities of which are focused on reducing the risk of global climate changes;
  - two experts with higher economic education with experience in funding of projects in the area of power generation;
  - an expert in the field of energy efficiency with higher engineering education;
  - an expert in the field of renewable sources with higher engineering education.";

The Management Board governs the overall activities of EERSF (adopts the internal regulations of the Fund; determines the Fund's financing and partial credit guarantee policy; adopts a business strategy for the activities of the Fund; approves the financing of energy efficiency projects, proposed by the Fund Manager etc.).

3. **Fund Manager**

EERSF is managed by a Fund Manager - a consortium of 3 private companies selected through a World Bank tender procedure:

- Econoler International (Canada) - worldwide operating energy efficiency consultancy company

  www.econolerint.com

- Eneffect Consult, part of Center for Energy Efficiency - one of the best established knowledge energy efficiency centers in Bulgaria

  www.eneffect.bg

- Elana Holding Inc. – the oldest and well-known financial non-banking institution in Bulgaria

  www.elana.net

4. **Executive director** – proposed by the Fund Manager and appointed by the Management board. Manages the day-to-day operations and administration of the Fund (incl. selection and development of commercially viable energy efficiency projects and preparation of the financial structure; develop, manage, and evaluate the product portfolio; manages EERSF's financial resources; performs monitoring, reporting and budgeting functions, etc.).

Projects

EERSF supports the identification, development and financing of viable energy efficiency and renewable energy projects, predominantly implemented in Bulgarian industrial enterprises, municipal entities and residential buildings.

The financial resources of EERSF are used to finance, but not limited to, the following type of investments:

- Investments in improved energy efficiency in industrial processes including but not limited to:

  - Purchase of equipment, machines and tools;
  - Technical assistance and advice for proper installment of the purchased equipment;
  - Training of staff in proper usage of the equipment and new technologies;

- Rehabilitation of buildings in all sectors, including but not limited to industrial, commercial, multifamily residential, single family residential and municipal buildings at all levels, health care facilities, schools, universities and cultural facilities. The rehabilitation should be directed towards improving energy efficiency**,** including but not limited to:

  - Modernization of heat exchanger substations;
  - Heating insulation, including new thermally insulated doors and windows, roof, ceiling and wall insulation;Solar window treatment and passive solar devices;
  - Improvements to mechanical heating ventilation and air conditioning such as customized controls and energy management systems, high-efficiency motors, variable-speed drive motor controls;
  - Improvements to interior and exterior lighting such as retrofitting of existing lamps and ballasts to high efficiency equivalents, addition of automatic lighting controls (i.e. timer or motion sensors);

- Improvements to the heat source and distribution system, including, but not limited to:

  - New high-efficiency boilers and burners;
  - Automatic boiler control systems;
  - Separate domestic hot water heaters for summer usage;
  - Substantial efficiency-driven modernization of existing boilers;
  - Boiler heat recovery devices;
  - New heat exchangers or substantial renovation of existing ones;
  - New main valves and steam taps or substantial renovation of existing ones;
  - New distribution piping or radiators;
  - New metering equipment;
  - Thermostatic radiator valves;
  - Pipe insulation in networks;
  - Small cogeneration systems;
  - High efficiency fossil fuel or electric-powered heat pumps.

- Rehabilitation of municipal facilities (e.g. street lighting);

- Other energy end-use applications, including but not limited to:

  - Energy management control systems;
  - Power factor correction measures;
  - Air compressors;
  - Fuel switching.

- In accordance with the new Energy from Renewable Sources Act the EERSF shall support renewable mainly off-grid projects. The aim is to be encouraged the implementation of small renewable energy projects for own heating, hot water and power supply.

Principal eligibility criteria

All energy efficiency projects should meet the following eligibility criteria:

- At least half of the project's benefits should come from measurable energy savings;

- The project should involve the application of well-proven energy saving technology;

- The project cost should range between EUR 15 339 and EUR 1 533 876 currently USD 19 597 – USD 1 959 682.

- The equity contribution of the Project Developer should be at least 10%;

- The project must have a relatively short payback time up to 5 years;

The eligibility criteria for renewable energy projects are still not fully determined. The Management board initially will take decisions case-by-case. The emphasis will be given to projects combining energy efficiency measures with renewable energy technologies. The target is to be encouraged projects for low-energy and zero energy buildings and facilities.

Financial policy and financial products

Loans:

EERSF provides loans for energy efficiency projects, as interest rates applied are lower than market ones, but still are commercially oriented. The interest rate applied is fixed for the whole period of credit. The borrower does not pay any banking taxes, including early repayment charges. The simple payback period of the projects financed should not exceed 5 years.

EERSF applies interest rates according to the credit market situation and the type of clients, currently adhering to the following rate range:

Type of client	Annual interest rate
Municipalities	**5 – 9%**
Universities and hospitals	**6 - 10%**
Corporate clients and individuals	**6 - 10%**

ERSF requires standard loan collateral: mortgage, pledge on movable property, claims on accounts and commercial contracts, financial risk insurance, bank guarantees, etc. The form of collateral and its size are defined according to the financial standing of the respective borrower.Currently EERSF does not apply future savings as collateral for loans to ESCO companies, because of difficulties with the repayment of the loans of such contracts in the past 2-3 years.

Guarantee products:

- **Partial credit guarantees**: EERSF offers collateralized credit guarantees, covering up to 80% of the project value to secure loans for energy efficiency projects contractors. Individual (per project) guarantee commitments shall not exceed **EUR 409 034**. Guarantees on greater amounts may be exceptionally provided after approval from the Management board.

The Fund Manager has developed specific financial products for the fast developing energy efficiency market in Bulgaria:

- **Portfolio guarantees for energy services (ESCO):** EERSF provides uncollateralized guarantee to a portfolio of receivables of energy services companies (ESCO) derived upon energy performance contracts (EPC). EERSF guarantees that it will cover up to 5% of the delayed payments of the portfolio covered.The absence of market demand for standard bank guarantees in 2008 forced EERSF to develop and offer 5% portfolio guarantees as a tool for encouraging the companies operating on the market for energy efficiency projects as ESCOs. At present EERSF has provided portfolio guarantees to 29 projects to the total value of EUR 8.9 million.

According to EERSF Operation Manual, the Fund Manager is responsible for the selection of appropriate financial tools on the basis of the specific circumstances of the project, the management's option concerning the general project profile, the correct distribution of risk among all the partners and the development of the domestic financial market.

Interest rate policy

The alteration of interest rates was consequence of the changes in interest rate percentages of credit in the bank sector in Bulgaria. The escalation of resources price in Bulgarian banks on one hand is due to Bulgarian National Bank measures to restrict the excessive credit growth, and on the other – as a result to the substantial increase of interbank interest rates, following the world financial crisis. In the future EERSF will carefully monitor the market conjuncture and will carry out measures with respect to maximum protection of its capitalization.

EERSF will continue to implement its "zero-fee" policy in the crediting of energy efficiency projects. Nevertheless, in 2007 an "engagement" fee was introduced for administration of all newly submitted potential projects. Currently, that administrative fee is set up in the limits of EUR 256 to EUR 511 depending on the size of the project. The guarantee is restored to the customer after the Management Board has made its decision on the respective project, irrespective of whether positive or negative, and is retained in favor of EERSF only in the event of an unwarranted stoppage of the procedure by the customer. The fee was introduced with the aim to save the Fund Manager's team time and efforts and to screen the customers, which do not have serious intentions to obtain credit.

Collateral on credit

The Fund Manager will continue to stick to the standard rules in the banking practice as regards the collateral in offering credits in order to minimize the credit risk for the EERSF portfolio, thus achieving or trying to achieve optimum ratio between solvency and credit risk. With that aim the Fund Manager will apply flexible approach in the acceptance of collaterals while broadening the possible modalities of eligible collateral. The currently used collateral is pledging of amounts receivable for municipalities, universities and hospitals (about 60% of the cases) and mortgages predominantly for corporate customers. As an additional security in the case of about 30% of the projects an insurance against financial risk has been signed.

Credit guarantees

Although the credit guarantees provided by EERSF are recognized by the Bulgarian National Bank as equivalent to bank guarantee, this product failed to find the expected market demand. This is due to a large extent to the coincidence in time of the launching of EERSF activity and the credit expansion of the commercial banks, which lowered abruptly their requirements in granting credits and collateral on projects. In their race for customers commercial banks most often preferred to lend the requested credit resource, even with certain compromises as to security, instead of requesting credit guarantees.

Under the conditions of financial crisis, in the early 2010 as expected there was increased interest in credit guarantees. EERSF offered credit guarantees covering up to 80% of the credit value for two projects, financed by Raiffeisenbank (Bulgaria) EAD. Total investment in these projects is EUR 2.2 million, and EERSF commitment is EUR 1.23 millions. In 2011 EERSF offered credit guarantees to Tokuda Bank, covering up to 80% of the credit value, thus all financial resources of the fund for guarantees are currently fully absorb.

Partnership with Banks and Financial Institutions

The initial concept about EERSF activities, which was laid down also in the document for its operative management, was based on the understanding for broad co-operation with commercial banks and co-financing of projects. That approach in indispensable and very important for EERSF, since its capitalization is relatively small. The success of EERSF in promotion of energy efficiency may to a considerable extent be supported through partnership with the banks.

Co-financing of the projects with the commercial banks leads to attainment of mutually beneficial effects for both parties, such as:

- The technical expert assessment by EERSF (which commercial banks cannot offer) provides grounds for diminishing of the risk related to project implementation.

- Commercial banks will take advantage of the reduced and shared with EERSF risk and ensure additional financing.

- Satisfactory risk level and profitability of the investments is achieved for both institutions.

- Additional capital for the EERSF projects is attracted.

At the moment EERSF has signed general framework agreements with 7 of the leading Bulgarian banks, some of them the largest commercial banks in Bulgaria – UniCredit Bulbank and DSK Bank.

As a result of the signed general framework agreement between EERSF and the International Asset Bank Plc the bank has emitted on the market two new credit products for energy efficiency: *"Energy Asset"* and "Energy Asset+". The credit products are structured entirely in compliance with the main requirements for project crediting by EERSF. The *"Energy Asset+"* credit product has been specifically designed for granting by the International Asset Bank of credits secured by a partial credit guarantee, issued by EERSF and covering up to 80% of the amount of the principal of the credit but not more than BGN 800 thousand.

EERSF credit portfolio status

The Fund has been operating successfully on a revolving principle already 6 years without major defaults. It successfully assists the implementation of the state policy in the scope of energy efficiency. The Fund's development and its further capitalization shall enforce provision of necessary resources for financing national and local energy efficiency programs.

At the moment the credit portfolio of EERSF is unbalanced by type of clients, as municipalities have 54 % share, corporate clients have respectively 33 % share, and universities, hospitals and others form at about 13 %. (see Fig. 1)

One year ago, corporate clients had advantage as per number of credits in the portfolio. The reduction of their portfolio respective weight is a projection of the reduced initial project proposals introduced by private companies.

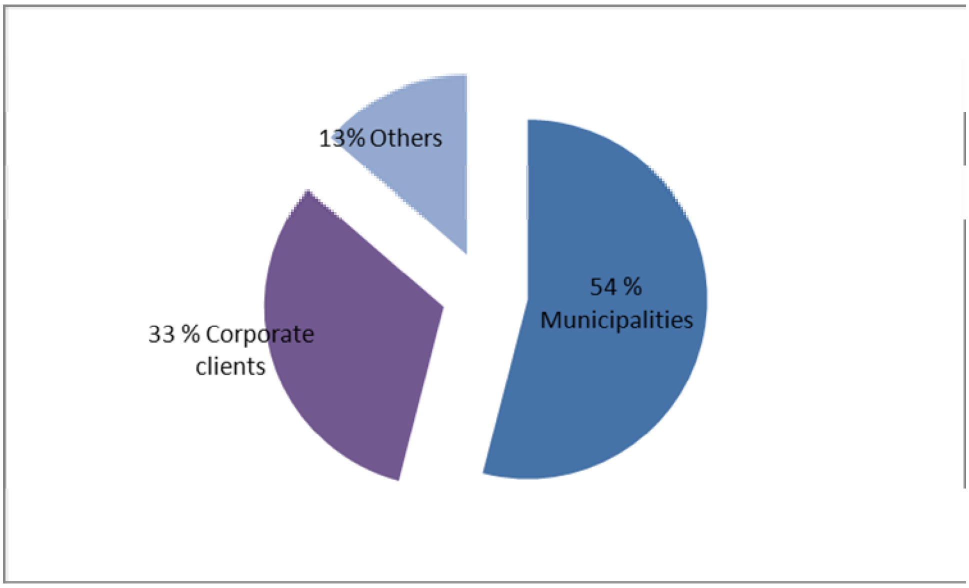


Fig.1: Type of clients distribution, December 2011

The distribution in size of projects and funding provided by EERSF, according to type of customer also indicates the dominance of municipalities over all other participants in the portfolio (Table 1).

Table. 1 Financed projects December 2011

Financed projects, December 2011

	Number of projects	Project value in %	Project size (EUR)	Project size in %	EERSF financing (EUR)	EERSF financing in %
Municipalities	67	54%	14 458 137	54%	9 849 323	53%
Corporate clients	40	33%	6 563 344	24%	4 535 928	25%
Others	17	13%	5 952 235	22%	4 122 740	22%
Total	**124**	100.0%	**26 973 717**	100.0%	**17 444 232**	100%

The reasons are objective:

On one hand the immersion of the financial crisis and its transformation into economic, brought to deterioration of financial indicators in all sectors of Bulgarian economy. In this severe economic situation and unsecure circumstances the companies naturally reduce their capital costs (including those for EE measures performance), which directly influences the number of projects financed by EERSF.

On the other hand EBRD provided credit line for energy efficiency and renewable energy sources - grants for projects to improve energy efficiency in industrial sector reached 15% of the amount of loans, which makes financing from commercial banks - attractive to end-beneficiaries. As for loans provided by EERSF the grant element is missing, the final price for borrowers is higher, which makes our competitiveness weak in attracting corporate clients.

Along with the reduction of project proposals by corporate clients for the last quarter there is another disturbing trend. The number of imported initial project proposals reduced by municipalities for the following reasons:

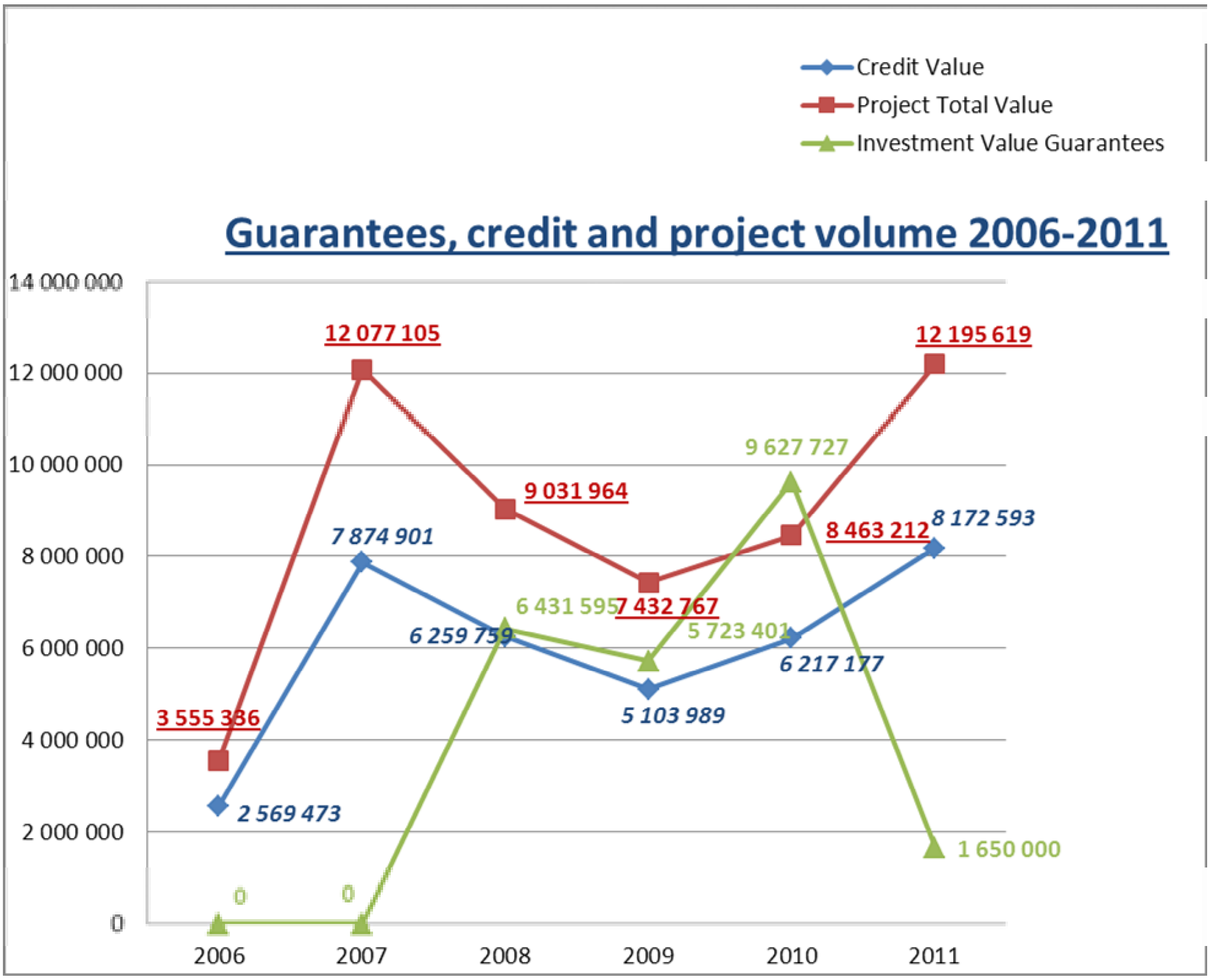
- Dramatic reduction in their revenue in local budgets. The last several years municipalities in Bulgaria enjoyed steady growth rate in their profit, due mainly to booming real estate transactions (and local tax for the transfer of real estate properties) and the sale of municipal property (mainly land) in increased interest from investors and higher prices.

- Cutting off the amount of government subsidies for the budgets of local authorities in municipalities deepens the complicated financial situation. This fact particularly troubles the group of small and medium-sized municipalities, which are the main target group of customers for EERSF.

- State Budget Act of 2011 set a lower limit on capital expenditures of municipalities: according to The Act for municipality debt – from 25% to 15% of total revenues and equalization subsidy. A significant number of municipalities exhausted or even exceed the limit.

However, Fig. 2 clearly shows the distribution of funded projects by years. The least value of financing is in 2006, when the Fund began operating - only 7% of the total portfolio.

The next year funded projects reached 23% share in EERSF six years credit portfolio - approximately four times the previous year. The next 2008, 2009 and 2010 have relatively the same level in financing EE projects while 2011 shows considerable growth.



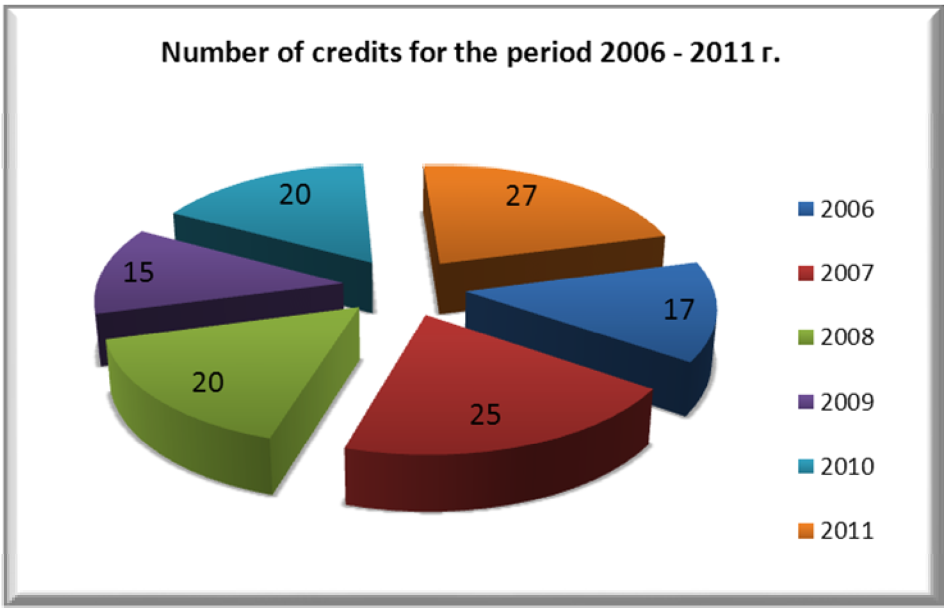


Fig. 2 Distribution of the years

Overdue and non-performing loans and guarantees paid under guarantee contracts amount to 13 % in December 2011 and are considerably lower than those in the banking system sector (23%). The structure of overdue and non-performing contracts is presented graphically in Fig. 3.

As the only non-performing loans of EERSF was claimed and paid insurance "financial risk" by Bulgarian Export Insurance Association, which covers 95% of principal and accrued interest. A lawsuit was brought for enforcement of collateral mortgage on real estate that is now interrupted by an insolvency proceeding to the customer.

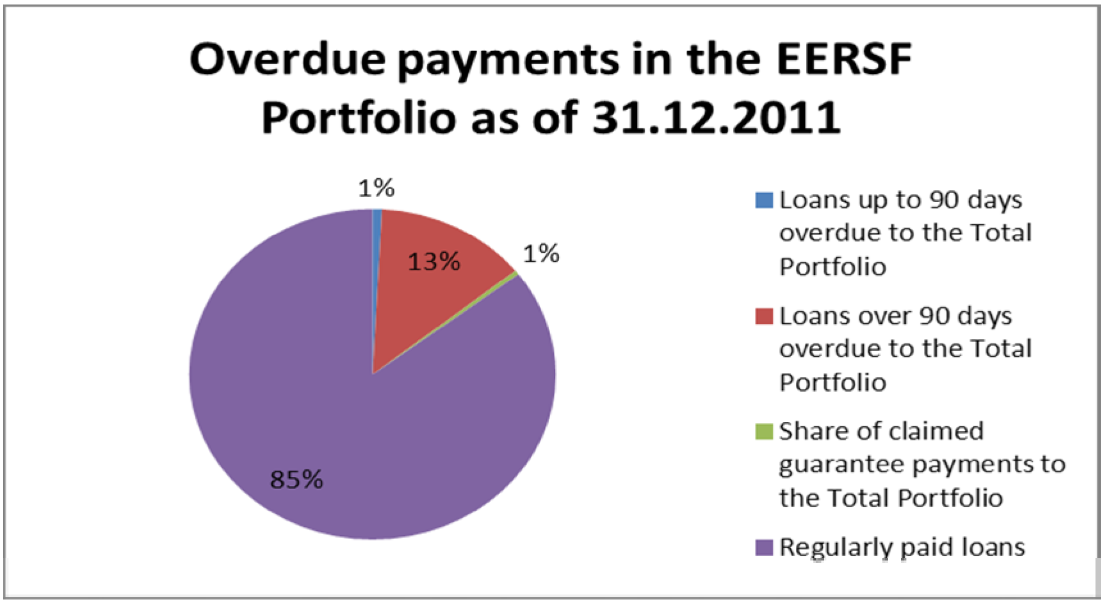


Fig. 3 Overdue credits and guarantees

EERSF Results, 2006-2011

<u>Summary Results of Energy Efficiency and Renewable Sources Fund as of December 2011</u>

I. Loans	Number of projects	Project size (EUR million)	EERSF financing (EUR million)
Projects financed	124	26.9	18.5
Municipalities	67	14.5	9.8
Corporate clients	40	6.5	4.5
Hospitals	8	4.2	2.9
Universities and others	9	1.7	1.1

II. Guarantees	Number of projects	Project size (EURmillion)	EERSF financing (EUR million)
Credit guarantees	31	11.1	1.7
Guarantees ESCO contracst (guarantees that EERSF will cover	29	8.9	0.3

up to 5% from the losses of portfolio of projects)			
Partial credit guarantees (on credit contracts)	2	2.1	1.3

Work with Customers

For the six years of its operation EERSF has managed to shape its own market niche for the energy efficiency projects. EERSF established itself as one of the leading financial institutions lending funding to the public sector – municipalities, hospitals, universities. With the amendments to the Energy Efficiency Act from 2007, municipalities received rights to apply directly for financing from the Fund instead of conducting time-consuming procedures for selection of financing institution. To this contributes the established cooperation with several national and regional organizations of municipalities, the Municipal Energy Efficiency Network "EcoEnergy" and National Association of Bulgarian Municipalities and business associations. The Fund has an active campaign for its loan products at local and national level.

The Fund continues to place a strong emphasis on financing of industry despite the objectively unfavorable economic environment. Due to the specifics of its credit products the Fund is preferred mainly by the small and medium-sized enterprises from the processing industry, the clothing industry and the hotel operators, which are regretfully among the Fund's customers worst hit by the crisis. The good contacts with different business and professional organizations, which were established in the previous years, help for collection of an ever bigger portfolio of projects of corporate customers.

In perspective a large portion of our efforts will be oriented towards attraction of universities as a target group, since according to our observations to date the Fund is the only financing institution, which provides loans for universities.

Despite the increased credit risk in 2010 EERSF envisages to gradually penetrate also the market for housing renovation. The signed Memorandum of Understanding with the Ministry of Regional Development and Public Works (MRDPW) and the United Nations Development Programme (UNDP) give us grounds to reckon that our efforts in that direction will be successful. We are approached ever more often by condominium associations, who seek implementation of their project on entirely commercial basis. In 2011 EERSF financed the first project for housing association renovation – building envelope retrofit, including energy efficiency measures as thermal insulation of roof, floors, external walls and replacement of windows.

Because of the specific rules of operation and crediting EERSF will be able to play an important role in the utilization of funds for measures for energy efficiency improvement and the use RES. EERSF will be one of the mechanisms for "bridge" financing of projects under the Operational Programmes "Competitiveness" and "Regional Development", ensuring in this way implementation of the projects irrespective of whether they have been approved under the EU Structural Funds.

Conclusion

The strategic task of EERSF will remain unchanged: financing ofmaximum number of viable projects for energy efficiency improvement. A major factor for EERSF's success till now has been the availability of a good portfolio of projects. The Fund Manager recognizes the importance of the availability of viable potential projects for the further development of the Fund and intends to increase its efforts in the direction of providing for a steady influx of projects in the future as well.

The operation of EERSF to date has been realized without considerable losses and delays under the credit portfolio and the set objectives of the Fund will be attained for its first six years of operation. But this situation does not resolve the basic question concerning EERSF's development in perspective. The need of increasing the Fund's capital and broadening of its sphere of operation in the direction of independent projects for energy generation from RES becomes ever more obvious. EERSF possesses the necessary technical expertise for evaluation of such projects. If it could ensure also the necessary additional capital it would be able to organize its activity in two parallel financial flows – energy efficiency and RES.

Major priority for the Fund Manager during the next years will be to activate the relations with other financial institutions for the purposes of co-financing of projects and diminishing of the credit risk. EERSF's financial resource is limited and its gradual investment in projects might lead to curtailing of its activity in the event of absence of temporary external financing. Attraction of more external funds in the form of loans from financial institutions and/or equity capital of the borrowers is indispensable.

What is missing?

- How has the found contributed to ESCO projects and ESCO development?

EERSF is the only institution that finances newly established ESCO companies, providing favorable conditions for collateral as financing risk insurance

- Do you keep track of the energy savings achieved by the found?

Yes, we have information system that is keeping track of all savings per projects and type of fuel, please see below the table.

EERSF Energy Savings 2011

	Electricity	*Heat Energy*	*Coal*	*Naphta/Diesel*	*Masut*	*Natural Gas*	*Prop./Butane*	*Wood*	*Wood briquet*
PER ANNUM	16 813 856 kWh	2 882 582 kWh	1 273 837 kWh	42 630 713 kWh	1 933 931 kWh	13 421 201 kWh	-1 916 474 kWh	428 009 kWh	-508 680 kWh
PROJECT LIFETIME	336 277 119 kWh	57 651 642 kWh	25 476 740 kWh	852 614 252 kWh	38 678 620 kWh	268 424 017 kWh	-38 329 480 kWh	8 560 180 kWh	-10 173 600 kWh

- Some example of projects in the commercial sector would be ok

All projects from the commercial sector are described in the web site, along with pictures of the completed projects. You can find all details at: http://www.bgeef.com/display.aspx?page=industry

Sources of information:

[1] *Global Environment Facility – Bulgaria Energy efficiency project, Project document 2005*

[2] Energy Efficiency Act Promulgated, SG No. 98/14.11.2008, effective 14.11.2008, supplemented, SG No. 6/23.01.2009, effective 1.05.2009, amended, SG No. 19/13.03.2009, effective 10.04.2009, supplemented, SG No. 42/5.06.2009, amended, SG No. 82/16.10.2009, effective 16.10.2009, supplemented, SG No. 15/23.02.2010, effective 23.02.2010, amended, SG No. 52/9.07.2010, SG No. 97/10.12.2010, effective 10.12.2010, amended and supplemented, SG No. 35/3.05.2011, effective 3.05.2011 / http://www.bgeef.com/display.aspx?page=profile

[3] Energy from Renewable Sources Act, Promulgated, State Gazette No. 35/3.05.2011, effective 3.05.2011 / http://www.bgeef.com/display.aspx?page=profile

[4] Presentation of the Energy Efficiency Fund project in Bulgaria at the World Bank web site / http://www.worldbank.bg/WBSITE/EXTERNAL/COUNTIRES/EC AEXT/BULGARIAEXTN/ 0,,contentMDK:21894153~pagePK:141137~piPK:141127~theSitePK:305439,00.html

[5] Bulgarian Energy Efficiency Fund Operational Manual

[6] World Bank Document, Implementation completion and results report (TF-54515)

Road to Green Data Centres - Developing eco-label criteria for energy efficient operation of data centres

Siddharth Prakash, Jens Gröger

Öko-Institut e.V. [1]

Abstract

Data centres, i.e. centrally operating facilities that process, store and distribute extensive volumes of electronic data, are the basis of our modern digital society. In Germany, data centres consumed about 9.1 TWh of electricity in 2007, i.e. about 1.7% of the total electricity consumption of the country [2]. This implies that almost four medium-sized coal-fired power plants would be required only for meeting the electricity requirements of data centres. Recent estimates suggest that energy consumption of data centres is expected to increase further in the next few years [3]. Against this background, the steering committee (Jury Umweltzeichen) of the German eco-label, the Blue Angel, commissioned the Öko-Institut e.V. to develop criteria for the energy efficient operation of data centres as a mean to contribute towards the reduction of greenhouse gas emissions and help in meeting stringent national greenhouse gas reduction targets. The criteria document of the Blue Angel "Energy concious data centre operation" addresses not only energy efficiency of individual components, such as servers, air-conditioners and uninterrupted power supply, but also puts its focus on the establishment and implementation of continuous energy monitoring. The aim is to motivate data centre providers to conduct regular energy measurements in order to detect inefficiencies and develop energy optimization measures.

This paper gives an insight in the development of the Blue Angel criteria for data centres, and provides information on technical and management features necessary to achieve energy efficient operation of data centres.

Introduction

Data centres, i.e. centrally operating facilities to process, store and distribute extensive volumes of electronic data, are the basis of our modern digital society. Some of the main functions of data centres include, handling the core business and operational data and functions of an organisation, offering off-site back-up services and providing data security, both electronic security in terms of encryption as well as physical security to prevent physical theft and vandalism.

Until recently, debate on data centres revolved mostly around measures to increase data centre performance. However, in the wake of increasing energy prices as well as imminent global impact of climate change, the focus has shifted towards increasing the energy efficiency and reducing greenhouse emissions of data centres. In Germany, data centres consumed about 9.1 TWh of electricity in 2007, i.e. about 1.7% of the total electricity consumption of the country [2]. This implies that almost four medium-sized coal-fired power plants would be required only for meeting the electricity requirements of data centres [4]. Recent estimates suggest that energy consumption of data centres is expected to increase further in the next few years, if current efficiency trends are maintained and no compensating efficiency measures are implemented by policy-makers, IT-manufacturers and data center operators [3].

At the same time, various studies indicate that there is enough technological potential available to substantially reduce the energy consumption of data centres [3], [5], [6]. Empirical evidence suggests that about 30 - 50% of the energy consumption of data centres can be attributed to the information technology (i.e. servers, external power supplies, switches, routers etc.), while the other half is related to the data centre infrastructure (building automation, air-conditioning, uninterrupted power supply etc.) required to support and provide IT-services [6], [7].

However, availability of reliable data substantiating the potential of energy efficiency measures in data centres is still poor. Apart from that, experts worldwide have not yet agreed on a common energy efficiency index for data centres, despite a proliferation of various metrices to measure energy efficiency of data centres (Table 1).

Table 1: Examples of metrices to measure energy efficiency of data centres

Green Grid [8]	Uptime-Institute [9]
• PUE (Power Usage Effectiveness): Total Facility Power/IT Equipment Power • DCIE (Data Centre Infrastructure Efficiency): IT Equipment Power/Total Facility Power x 100%	• SI-EER (Site Infrastructure-Energy Efficiency Ratio): Ratio of total energy consumption to energy consumption of IT • IT-PEW (IT Productivity per Embedded Watt): Ratio of IT-productivity (transactions, storage volume etc) to required power

The Green Grid: GREEN GRID METRICS: Describing Datacenter Power Efficiency. Technical Committee White Paper, February 20, 2007; Brill, Kenneth G.: Data Center Energy Efficiency and Productivity, White Paper, The Uptime Institute, 2007

Against this background, the steering committee (Jury Umweltzeichen) of the German eco-label, the Blue Angel, commissioned the Öko-Institut e.V. to develop criteria for the energy efficient operation of data centres as a means to contribute towards the reduction of greenhouse gas emissions and help in meeting stringent national greenhouse gas reduction targets. The criteria were developed between January 2010 and May 2011 in a broad stakeholder process, involving data centre providers, component manufacturers, academic experts, environmental organisations and public authorities. The development of criteria was aligned with similar efforts elsewhere, such as the EU Code of Conduct on Data Centres and the Green Grid Initiative. The criteria documentwas published in July 2011 on the website www.blauer-engel.de.

Data centre management is not interested in energy efficiency measurements!

The major challenge for implementing energy efficiency measures in data centres does not lie in defining technology-oriented solutions, but in executing energy-oriented management processes. A major part of data centre operators is not in a position to provide any information on the energy consumption of the total facility as well as of IT [10]. According to a study conducted by the German Internet Industry Association (eco), only 33 % of all data center operators have staff which deal with the subject of energy efficiency and at least 37.5 % of the data center operators boasts a responsible officer who keeps track of the current costs for the IT in the data center. Furthermore, 31.25 % of all data center operators still work without a separate budget. However, it is a well-accepted notion that continuous measurements and monitoring of energy consumption of IT and data centres leads to the identification of opportunities for reducing energy consumption and associated costs.

The Blue Angel Eco-Label for Energy-Concious Data Centres – Focus on energy monitoring!

In order to address the lack of knowledge and interest in implementing energy efficiency measures in data centres, the Blue Angel eco-label for energy-conscious data centers, was published in Juli 2011 [11]. It is awarded to data centers whose operators advocate the implementation of a long-term strategy to increase energy efficiency with respect to the IT services to be provided. Moreover, the Blue Angel ecolabel serves as an instrument for informing clients and technical staff of the data center in order to raise their awareness of the necessity for the implementation of energyefficient measures at data centers. Thus, the focus of the Blue Angel award crietria lies not only in the energy efficiency of the individual components of the data centers, such as IT technology, power supply and air conditioning but also the promotion of continuous energy monitoring. It also has the aim is to motivate the data center operators to regularly monitor the electricity consumption in order to be able to discover the inefficiencies at the respective data centers and to derive possible improvement measures. In the future revision of the criteria document, it is expected that the Blue Angel might set concrete benchmarks in terms of energy efficiency standards, if data availability is improved.

Figue 1 The Blue Angel Eco-Label for Energy-Concious Data Centres, www.blauer-engel.de

In order to be awarded with the Blue Angel label, a data centre operator is obliged to measure the Energy Usage Effectiveness (EUE) of its data center for a reporting period of 12 months. The end of the 12-month measurement period shall not date back more than 3 months at the time of application filing.

The EUE describes the ratio of energy demand ($E_{data\ center,a}$ [kWh/a]) of the entire data center to the energy demand of IT ($E_{IT,a}$ [kWh/a]) over a period of one year.

$EUE = E_{data\ center,a}$ [kWh/a]/ $E_{IT,a}$ [kWh/a]

At the same time, the EUE is the average PUE (Power Usage Effectiveness) over a certain reference period - within the framework of the Blue Angel over the past 12 months.

$EUE = PUE_{average} = E_{data\ center} / E_{IT}$

Furthermore, he is deemed to report the current state of the data centre and provide technical and energy relevant data to a competent body, and establish an energy management system according to DIN EN 16001. The energy management system shall include at least following points:

- an energy strategy has been set out in writing,
- the energy-saving measures are viewed and developed cross-divisionally (IT procurement, IT operations, building management, energy controlling, purchasing and, if applicable, sales),
- the responsibilities for optimizing energy use are clearly defined,
- an ongoing improvement process for optimizing the use of energy is in place, and
- efficiency improvement goals have been defined and the achievements in pursuing these goals are monitored.

The Blue Angel label document defines strict measurement points for monitoring of electrical energy, temperatur and IT-load ((CPU load [%], RAM workload [%]), memory (storage/disk space [%]) and network (bandwidth [%]), as shown in Figure 2.

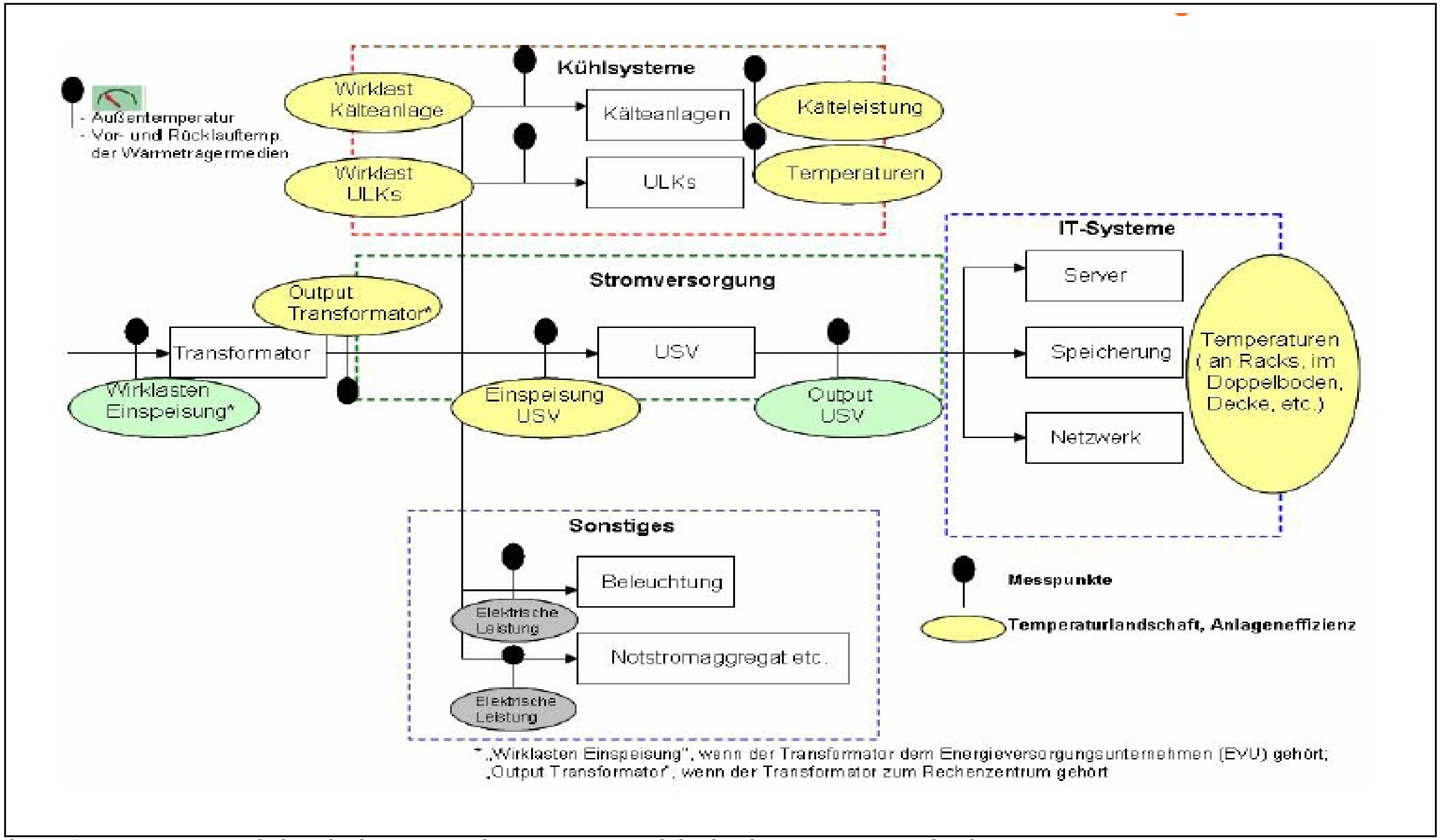


Figure 2 Measurement of electrical output and temperatures of the basic components of a data center,

(Source: deZem 2009 [12]; adjusted by the German Öko Institut 2010)

Apart from that, the applicant seeking a Blue Angel label is required to present an annual Energy Efficiency Report. The report shall give the changes since the initial application. It shall document not only the development of the Energy Usage Effectiveness (EUE) over the period of label use but also the changes in the other energy efficiency measures.

Other excellence criteria of the Blue Angel Eco-Label

Data centre operators applying for the German Blue Angel Eco-Label are also expected to perform an Energy Conscious Procurement by undertaking a life cycle cost calculation over the period of use (investment costs, maintenance and energy costs) when buying new equipment and devices, such as servers and external power supplies. For instance, when buying new servers during the life of the Contract on the Use of the Eco-Label the total energy efficiency of the servers (• ssj_ops/ • power) shall be determined under the SPECpower_ssj2008 methodology and shall, at a minimum, be 2,000 [13]. Furthermore, the minimum efficiency (at 20%, 50% and 100% load) of newly acquired power supplies installed in IT equipment shall meet the requirements of the 80 PLUS GOLD efficiency standard [14].

Apart from that, , award criteria encompass stringent conditions for server room temperature (minimum 28 ° C), chiller efficiency (Energy Efficiency Ratio of 4, Seasonal Performance Factor of 3.5), modularity of computer room air-conditioners and efficiency for uninterrupted power supply. The criteria demand, for instance, that the cooled supply air temperature at the computer room air conditioner(s) (CRAC) must not fall below 18°C (with exception if free cooling is used exclusively), and the exhaust air temperature at the computer room air conditioner(s) (CRAC) shall be at least 28°C. Potentials of efficient cooling are further realised by requirements for hot/cold aisle configuration, where the racks shall be installed front to front as recommended by VDI 2054 or the ASHRAE Technical Committee 9.9, and complete hot/cold aisle containment shall be guaranteed.

Furthermore a series of energy-saving recommendations (non-binding) are made in order to help interested parties enhance their understanding of energy efficiency measures in data centres. They are of non-binding character because the complexity and diversity of the system design of data centers does not allow a fixed and predefined general solution for improving energy efficiency. Otherwise, innovative overall solutions might be neglected or taken into account only insufficiently. This approach allows the consideration of both newly established data centers and existing ones, each with very different energy efficiency concepts.

Conclusion

The main aim of the Blue Angel Eco-Label for Energy-Concious Data Centres is to motivate data centre providers, to conduct regular energy measurements and install a monitoring system in order to detect inefficiencies and develop energy optimization measures. In the wake of increasing energy prices as well as imminent global impact of climate change, such a step helps in reducing costs and greenhouse gas emissions. The Blue Angel Eco-Label shows, how to achieve this goal, not with heavy investments, but with proper long-term planning and management of data centres. Now, it is up to the data centre providers, small, medium as well as large-sized, to adopt the Blue Angel Eco-Label to set a sign for a new climate strategy.

References

[1] Öko-Institut e.V. Website: www.oeko.de.

[2] Stobbe et al. (2009) : Abschätzung des Energiebedarfs der weiteren Entwicklung der Informationsgesellschaft, Fraunhofer IZM und Fraunhofer ISI, commissioned by the Federal Ministry of Economics and Technology, Berlin

[3] Fichter, K. (2007): Zukunftsmarkt energieeffiziente Rechenzentren, commissioned by the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU), Berlin.

[4] Umweltbundesamt (2009): Green IT: Zukünftige Herausforderungen und Chancen, Background Paper of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU), the Federal Environment Agency (UBA) and the Federal Association for Information Technology, Telecommunications and New Media (BITKOM), Dessau

[5] U.S. EPA (U.S. Environmental Protection Agency, Energy Star Program) (2007): Report to Congress on Server and Data Center Energy Efficiency, Public Law 109-431, August 2, 2007

[6] Behrendt et al. (2009): Konzeptstudie zur Energie- und Ressourceneffizienz im Betrieb von Rechenzentren - Studie zur Erfassung und Bewertung von innovativen Konzepten im Bereich der Anlagen-, Gebäude- und Systemtechnik bei Rechenzentren, Technische Universität Berlin und Innovationszentrum Energie (IZE), Berlin

[7] Rasmussen, N. (2006): Implementing Energy Efficient Data Centers, White Paper 114, American Power Conversion (APC)

[8] The Green Grid: GREEN GRID METRICS: Describing Datacenter Power Efficiency. Technical Committee White Paper, February 20, 2007

[9] Brill, Kenneth G.: Data Center Energy Efficiency and Productivity, White Paper, The Uptime Institute, 2007

[10] eco – Association of the German Internet Industry e.V.(2008): Evaluation of efficient computer centers in Germany, www.eco.de.

[11] The Blue Angel for Energy-Concious Data Centres, RAL-UZ 161, Website: http://www.blauer-engel.de/en/products_brands/search_products/produkttyp.php?id=598

[12] deZem (2009) Green IT - pragmatisch und nachhaltig durch neuartige Transparenz im RZ-Betrieb, Presentation by Dr. Georg Riegel, CEO, deZem GmbH, at the Data Centre Convention, Cologne 2009

[13] www.spec.org/power_ssj2008/

[14] http://www.80plus.org/manu/psu/psu_join.aspx

From technically feasible to realizable energy efficiency potential in Norwegian non-residential buildings.

Dr. Håvard Solem

Enova SF, Norway

Abstract

Energy efficiency is acknowledged as key to achieving reductions in climate gas emissions and to secure energy supply. The barriers, however, are many as they go from technical to economical, and in the end reflect the behavioral aspects of the actors' decision making. In order to prescribe effective measures the authorities must have in-depth knowledge about the mechanisms behind what hinders and triggers energy efficiency decisions. Our analysis shows how energy efficiency potential can be decomposed into technical, economic and realizable potential for energy efficiency. First, the status of the building stock is assessed by disaggregating the total floor space into building categories divided into groups by age. This is the basis for assessing the technically achievable efficiency potential. Second, the amount of saved energy is combined with energy prices and held against the costs of upgrading to identify the economically feasible potential. Further, we observe that profitable energy efficiency projects are not implemented, and at the same time a number of efficiency measures that are not profitable are actually implemented. The implication is that the realizable potential is not a straight forward disaggregation of the economic potential. It is therefore paramount to understand the behavioral aspects of the market actors' decision-making processes. The third stage is therefore to reveal the non-economic and non-technical elements that hinder implementing of efficiency measures. These have been identified through focus group studies, in-depth interviews and surveys. The fourth stage is to determine the realizable potential with evidence from Norway.

Introduction

It has long been acknowledged that improving the energy efficiency of buildings is an important step to strengthen security of supply and help reduce greenhouse gas emissions [1]. In Norway, this has been reflected in the climate agreement that was signed by a majority of the political parties represented in Parliament. This has resulted in an environmental action plan for the housing and construction sector that point to sharpening of energy requirements in the national building codes on a regular basis. The goal is that the requirements are to be at passive house level by 2020[1]. We have however seen resistance towards this plan from different market actors, increasing the political cost of committing to implementation of such an ambition.

Political ambitions beyond Norwegian borders are not less ambitious. At EU level, it is stated that new buildings should have an energy performance at nearly zero energy level by 2020. Norway has implemented a number of EU directives that have implications for energy use in buildings, such as the Energy Performance Buildings Directive (EPBD) (2002/91/EC), Renewable Energy Directive (09/28/EC), Eco-design Directive (2005/35/EC). The Energy Services Directive (2006/32/EC) and the EPBD recast (2010/31/EC) are not implemented yet.

---

1 The passive house concept is based on minimizing heat demand. Heating is based on passive use of natural heat sources, such as from the sun, body heat and electrical appliances. In 2012 a Norwegian passive house standard for commercial buildings will be launched.

A number of reports have identified the potential for energy efficiency in residential and non-residential buildings. On the 23 August 2010 the Norwegian Ministry of local government and regional development [2] received a report from a special appointed task force concluding that it is realistic to reduce energy consumption for the operation of buildings by 10 TWh per year by 2020. By 2040 it is said that it is possible to halve energy use, equivalent to a reduction in final energy use by 40 TWh per year[2].

The various reports have based their analysis on investigating the average of the building stock. Since we know that there are large variations in the energy performance between building categories and ages, we have analyzed the technical and economic potential for energy efficiency taking this into account.

When it comes to the analysis of barriers standing in the way of increased levels of energy efficiency we point to key factors inflecting on the size of the realizable potential. Our conclusion is that it is important to be aware that different barriers play important roles for different groups of stakeholders. The individual building owner faces a different set of barriers compared to the construction industry, which in turn is different from the barriers from government's point of view.

The basic conclusion is that we can quite accurately estimate the technical and economic potential. However, taking into account the real life situations that the market actors find themselves in, the realizable potential is a far less accurate number. We know for instance that there are a lot of energy efficiency measures that are profitable that are never implemented and at the same time we see implementation of efficiency measures that are not profitable. Insights about the mechanisms behind this are used to estimate a realistic potential for energy efficiency in non-residential buildings.

The building stock in 2010 and 2020

Both technical and economic potential will vary with the type of building category and the current level of energy performance for each category of buildings. In order to quantify the energy efficiency potential the total commercial building stock was disaggregated into 11 building categories identical to those used in the national building code regulations (denoted TEK and a to-digit number indicating the year when they was implemented). Further, the total number of square meters within each building category is allocated to the various construction periods based on historical changes in technical regulations.

In order to say something about the current level of energy performance the disaggregation of the building stock is adjusted for renovation, remodeling and other activities that affect the buildings energy use. In fact, a large proportion of the buildings that exist today have undergone extensive rehabilitation, and as a function of this has an improved level of energy performance. On the other hand, we have not sufficient statistical data to quantify exactly how many square meters that are rehabilitated each year, or how large the reduction in energy use following from this actually is. Instead of assuming a fixed rehabilitation rate for all building categories, each building category is considered separately, and we have estimated a fraction of the building categories that normally will be rehabilitated within each age group.

For example, it is assumed that the majority of buildings constructed before 1949 is restored to a better energy performance. Further, it is estimated that 60 percent of cultural buildings are rehabilitated whereas 90 percent of the hospitals have gone through rehabilitation to a better energy standard due to the various reforms that have been implemented. The Working Environment Act came in the 1970's, which in turn led to the various upgrades of hospitals, schools and kindergartens, to a different extend compared to cultural buildings. Our analysis suggests that various industrial buildings have not undergone rehabilitation in a large scale.

Statistics Norway predicts that the population in Norway will be 5.4 million people in 2020. To compensate for buildings that are demolished an increase of new buildings by 15 percent over a ten

[2] In 2009 electricity accounted for 80 percent of the final energy demand in commercial buildings [3].

year period is needed, implicating a rate of approximately 1.5 percent per year. On the basis of the estimated rehabilitation and new construction rate up to 2020 Table 1 shows the distribution of the total area of building categories and age groups.

Table 1 Total area in 2020, including demolition, rehabilitation, new construction. Square meters.

Age groups	2010-2020	2007-2010	1997-2006	1987-1996	1969-1986	1949-1968	-1949	Total in 2020
Kindergarten	182 800	85 900	306 000	337 700	418 000	47 200	16 600	1 394 200
Office buildings	3 837 000	762 700	3 718 600	6 742 000	8 717 000	4 258 400	1 232 400	29 268 100
Schools	1 990 100	676 600	2 720 400	3 285 800	4 290 300	2 069 200	148 300	15 180 700
University/colleges	349 800	95 200	351 700	451 500	955 400	426 200	38 300	2 668 100
Hospitals	681 300	275 800	1 041 000	1 104 500	1 260 200	700 200	133 500	5 196 500
Nursing homes	747 600	614 400	1 614 700	1 261 500	1 213 900	241 200	9 300	5 702 600
Hotels	819 100	303 500	1 097 100	1 483 900	1 839 000	667 100	38 200	6 247 900
Sports building	333 000	93 900	321 000	429 400	1 059 800	298 800	4 300	2 540 200
Commercial buildings	4 354 300	1453 000	5 112 500	7 181 400	11189 600	3 681 100	242 200	33 214 100
Cultural buildings	415 600	64 300	392 900	699 200	733 000	350 300	514800	3 170 100
Industrial buildings	1 391 400	191 400	958 300	2 024 300	3 947 000	1 523 600	577 500	10 613 500
Total	15 102 000	4 616 700	17 634 200	2 500 1200	35 623 200	14 263 300	2 955 400	115 196 000

Energy performance

To find a representative specific energy use for different building categories and age groups a representative building shape and size is defined. Separate calculations are performed for each efficiency measure taking into consideration operational conditions. Replacements and minor upgrades done during the time the buildings have existed are also included. For example, few old buildings still have lighting equipment from the construction year as in most cases it has been replaced. The energy performance for each building category and age group is reported in Table 2.

The buildings' calculated energy demand is converted to the amount of delivered energy required based on an analysis of the heating system and system efficiency. The calculation of the energy performance of the building stock thus takes into account that the buildings generally are not operated optimally. In total the existing stock of non-residential buildings in 2010 uses a total of 35.4 TWh per year, consisting mostly of electricity.

Table 2 Estimated energy delivered per building category for current and historical building codes. kWh per square meter.

Building code	TEK 10	TEK 07	TEK 97	TEK 87	TEK 69	TEK 49	Older
Kindergarten	104	146	209	318	395	426	431
Office buildings	114	157	218	295	308	304	311
Schools	93	135	198	289	304	293	314
University/colleges	119	169	239	320	330	286	304
Hospitals	209	309	426	546	446	335	352
Nursing homes	162	239	331	463	381	335	355
Hotels	154	224	323	436	402	353	374
Sports building	126	170	253	372	464	420	453
Commercial buildings	165	252	363	477	318	290	306
Cultural buildings	114	162	240	331	323	321	344
Industrial buildings	128	176	253	357	475	425	458

For new buildings, the potential is derived from measures that raise the energy performance from the present building code level (TEK 10) to low energy levels[3].

Technical potential

The technical potential is the potential that is technically feasible. When calculating the technical potential one must take into account that a given proportion of the existing building stock in each age group cannot reach TEK10-level. It is estimated that 15 percent of the total building stock will not be able to reach a higher standard than the level prescribed by the technical code of 1987 (TEK87) without major modifications to the load-bearing construction. This also includes buildings where restrictions due to preserving the cultural heritage that they represent. This applies mainly to the relatively older buildings.

The estimated energy consumption in commercial buildings in 2010 is compared to the level of energy use derived from a hypothetical situation where the building stock was performing at the level of the current technical building code (TEK10). Our analysis shows that if every existing building was raised to TEK10-level the technical potential would be 19.5 TWh per year. This represents a hypothetical reduction of 55 percent.

The estimated technical potential is shown per building category and TEK-level in Table 3 below. It is clear that the greatest technical potential is found in commercial retail buildings, followed by office buildings, industrial buildings and school buildings. This is primarily driven by the fact that these categories accounts for the largest amount of existing square meters, not necessarily that potential savings in each building are greatest in this construction category. If one looks only at the specific savings potential the largest potential is found for industrial buildings, sports hall and kindergartens. It is important to point out that one will observe deviations from these numbers when assessing the potential in a specific building.

Table 3 Technical potential for energy efficiency in 2020. GWh per year.

Building code	TEK 07	TEK 97	TEK 87	TEK 69	TEK 49	Older	New buildings	Total
Kindergarten	3	29	71	118	11	4	9	246
Office buildings	32	381	1267	1 625	578	165	169	4 218
Schools	28	262	625	861	281	22	85	2 164
University/colleges	5	42	94	192	49	5	16	403
Hospitals	27	220	377	279	54	12	43	1 011
Nursing homes	46	249	361	248	27	1	47	978
Hotels	21	180	429	429	85	5	56	1 205
Sports building	4	37	104	342	61	1	17	566
Commercial retail buildings	124	996	2301	1 607	298	22	358	5 705
Cultural buildings	3	48	158	148	49	78	26	510
Industrial buildings	9	115	486	1 327	316	131	84	2 468
Total	301	2 558	6 275	7 176	1 809	445	911	19 475

[3] Low energy is a level defined in a report from [5] and reflects an energy performance between the present building code level and passive house level.

Economic potential

The economic potential is the share of the technical potential that generates an acceptable return on the investment, given investment costs, energy prices, the measure's economic life-time and discount rate. In the analysis the economic potential reflects measures that show a positive net present value.

Investment costs are taken from a calculation standard widely used in the Norwegian construction sector, where this has been applicable. Otherwise, the costs are estimated on the basis of empirical data based on information obtained from tenders for rehabilitation and new construction projects. Input values for energy savings and the investment cost is described by probability distributions. This is done to reflect the variation in prices that we observe in the market, and the variation in expected reduction in energy use found between buildings.

The calculations are done for a calculation of interest rate equal to 4, 7 and 10 percent, respectively. Discount rate reflects the fact that future benefits and costs are not valued as highly as the benefits and costs today. In other words, the discount rate is the return of capital in the best alternative use. Discount rate is thus the cost of capital to the project. This means that the higher the discount rate is, the higher the required return to action. The choice of the level of the discount rate is important for the measures that have positive net present value. What rate of return different actors requires will vary, and there will also be uncertainty about future energy prices.

Assuming an energy price of 0.8 NOK per kWh (app. 0,1 €/kWh), excluding value added tax, and an annual discount rate of 7 percent the overall economic potential amounts to approximately 9 TWh per year. If one calculates with a range of energy prices of 0.8 to 1.4 NOK/kWh the economic potential varies in the order of about 3 TWh. Similarly, the potential will vary in the same order of magnitude for a range in the discount rate of 4 to 10 percent.

A breakdown of the economic potential distributed on different building categories and age groups are shown in Table 4. A comparison between the economic and technical potential shows that the maximum technical potential lies in improving the building envelope, but as expected, the economic potential for this type of measures is significantly reduced considering the relatively high investment costs. The greatest economic potential lies in measurements improving ventilation measures, followed by measures aimed at optimal use of the building.

Table 4 Economic potential given an energy price of 0.8 NOK per kWh excluding VAT (app. 0,1 €/kWh) and an annual discount rate of 7 percent. GWh per year.

Building code	**TEK 07**	**TEK 97**	**TEK 87**	**TEK 69**	**TEK 49**	**Older**	**Nybygg**	**Total**
Kindergarten	2	16	35	34	5	2	1	93
Office buildings	17	186	571	407	218	73	27	1498
Schools	15	145	317	195	112	10	8	801
University/colleges	2	21	45	47	20	2	3	141
Hospitals	16	149	240	78	33	7	15	538
Nursing homes	27	156	211	53	12	1	11	470
Hotels	11	94	221	112	40	3	15	497
Sports building	2	19	50	110	27	0	3	212
Commercial buildings	96	774	1570	690	179	13	172	3494
Cultural buildings	2	22	74	42	22	40	5	207
Industrial buildings	5	54	224	489	157	71	17	1016
Total	**195**	**1635**	**3560**	**2257**	**825**	**221**	**275**	**8967**

Energy efficiency barriers

An analysis of realistic energy efficiency potential must include a good understanding of the determinants of behavior at the individual and corporate level, structural factors in the construction and property sector and how different policy measures work individually and affect on each other.

There are some main points that are important to bear in mind when assessing barriers for energy efficiency:

- *The relevant societal level.* Barriers from the government's point of view may not be acknowledged as a barrier from the construction sector's viewpoint. For example, lack of competence needed to construct buildings with an energy performance better than the majority of the market demands are not necessarily a barrier for the individual business, but is so in the eyes of government.

- *Interdependencies between barriers.* Addressing only one barrier is not the efficient approach as different elements affect each other. For example, the awareness about the economic potential from energy efficiency measures is low because of insufficient competence in the construction sector on how to reduce energy use, which in turn is caused by the general negative attitude in the market towards investment in energy efficiency measures. Behind this lies the lack of good examples with sufficient documentation of the benefits from reducing the energy use in buildings.

- *Market segmentation.* A useful reference is the well-known curve showing the steps in technology diffusion [4]. In brief, it can be used to show that a segmentation of market actors in relation to the ability and willingness to adopt new solutions also shows the strength of various barriers between segments. For example, a new solution is not necessarily competitive in an economic sense, but it is demanded by early adopters because of preferences other than purely economic ones. This may include factors such as environmental, social status, or a general interest in new technology. The most effective market transformation strategy is to address the strongest barriers relevant to the market segment that drives the transition in to the mass market.

To reveal barriers hindering implementation of energy efficiency measures we carried out case studies, in-depth interviews and focus groups. The general impression is that it is particularly the economic barriers that stand out as an important and major obstacle. Further, there are several individuals who stated that there is insufficient expertise and knowledge related to how energy efficient buildings will be operated, and what the benefits of energy conservation are. Many believe it is lack of knowledge among operational personnel, and that it is challenging to retrain janitors to also be able to work with relatively advanced systems for energy conservation. It was also pointed out challenges to deal with conflicting regulatory requirements related to energy conservation and indoor air quality. Barriers related to myths and preconceived attitudes to energy conservation are a barrier that many believe is linked to lack of knowledge, and which may be the cause of cost inefficiency.

Respondents in focus groups and case studies were also asked to identify at what point in the decision-making process the various barriers occur. The general impression is that the economic barriers dominate in the early stages. In the design phase, it is the practical and technical issues that arise as hinders. In the execution phase it may seem as if there is a lack of knowledge and sufficient competence that is among the biggest barriers.

Participants in the focus groups also felt that there are significant barriers that companies themselves can influence. Such barriers would be the lack of focus and awareness within the organization, expertise and knowledge of operating personnel and knowledge about energy use in buildings.

Key factors affecting the realizable potential

Analyzing the barriers individually is not an approach that provides a good basis for estimating the real potential. Furthermore, the effect of evaluating each barrier individually will be different from a holistic analysis encompassing all mechanisms that prevent realization of the energy efficiency potential. This is because the barriers on one hand operates at different levels, from the attitudes of the individual to the corporate structure, and on the other hand interacts in a way that have impacts on the overall potential.

Looking at this in a larger perspective, it is interesting to see how the decisions of the individual building owner may be affected by the interaction between market mechanisms and public policy measures.

An example is the following situation: whereas the building owner is the one who can invest in the building it is the tenant that in most cases will capitalize on the reduced energy costs. Furthermore, we also know that owners of commercial buildings are concerned about the value of their buildings. The value is a function of the building's attractiveness in the market, which is reflected in the lease level. The resulting connection between willingness to invest and energy efficiency is found in the connection between the tenant's willingness to pay above normal lease for a building with lower operating expenses. And the willingness to pay for this is dependent on, and is triggered by, that the reduced operating costs can be documented. In addition, there are non-energy benefits such as a positive contribution to building the firm's corporate social responsibility from being located in a building with an environmentally friendly profile.

There are various ways to document the building's environmental performance. Energy labeling schemes are examples of a system that ensures that the energy performance documented. There are also environmental classification systems that document the environmental performance such as LEED and BREEAM.

Such schemes will not by themselves trigger a substantial degree of market transformation. The challenge is that if a large majority of the buildings in the market are classified at about the same level in the classification system, this will not be able to create a sufficient difference between buildings. It is only when the customer can choose between buildings with different energy performance that this will affect the valuation of the buildings.

At the sectoral level Porter's theory about successful clusters can serve as a backdrop when discussing the possibilities for obtaining higher future economic returns through greater competitiveness based on improved energy efficiency performance. The opportunities for the commercial buildings sector are related to the following elements:

- Innovative companies who dare to invest in new solutions.
- A strategy based on building competitiveness through capacity building and cost efficiency by developing and adopting new solutions.
- Identifying growing market segments responding to benefits accruing from energy efficient buildings.

Elements that must be present to realize the energy efficiency potential is in addition related to:

- Increased knowledge and awareness of energy efficiency.
- Availability of tools required for documentation of energy performance.
- Lease agreements governing the relationship between landlord and tenant.
- Innovation as a result of demanding customers.
- Development of skills that are complementary, i.e. they can be used by a large proportion of businesses in the sector.
- Distribution of knowledge among the different market actors through the value chain brings experience and knowledge to even more new projects and customers, and sets requirements for subcontractors.

What is technically possible to do in order to increase energy efficiency and the subset of measures that are economically profitable must be analyzed in more real life situations. Only in that way can we talk about realizable potential.

It is not a given thing that specific barriers are perceived in the same manner from the perspective of the individual building owner, construction sector as a whole or government. For example, we have many buildings where it from society's point of view would be profitable to rehabilitate to a better energy performance, but where owners simply do not see any economic reasons to invest. If a market actor has no motivation to include external benefits into their calculation or is aware of the benefits arising from investing in energy efficiency, we can not say that they themselves experience any barriers hindering energy efficiency. For society, however, is the property owner's lack of awareness and knowledge about energy and insulation of homes significant barrier to important energy policy objectives.

Concluding remarks

Based on our analysis we present the following claim:

A barrier materializes only when the decision maker is in a mode where the specific energy efficiency behavior is a known and possible outcome of a decision process.

The first point is that the real potential cannot be compared directly with the economic potential of two reasons. First, the implementation of economically profitable single measure does not automatically happen because you may not be in a mode to do something with your building. In other words, you have not considered the possibility to take action, regardless of potential economic profitability. Furthermore, in some cases the benefits of an energy efficiency measure does not necessarily outweigh costs in form of hassle and annoyance. Second, we could see an effect of a rehabilitation project in terms of implementation of unprofitable efficiency measures as the rehabilitation is motivated by the need for a general upgrade and not energy performance in itself. Consequently, we see that efficiency measures are implemented without the need to be economically profitable.

Our next conclusion is therefore:

The realizable potential is necessarily not a subset of the economic potential.

So in order to say something about how much of the technical potential it is realistic to trigger we identify two key factors:

- Planned rehabilitation
- Increased rehabilitation rates

In Norway, as in a number of other countries, there is a large gap between what actually is being rehabilitated and what *should* be rehabilitated when all costs and benefits are considered.

The rehabilitation rate is difficult to estimate as there is not sufficient data available. Rough estimates suggest that 1.5 % is rehabilitated in addition to the 2 % of buildings that undergo less comprehensive rehabilitation. Using the estimates of square meters within each building category and age group, together with assumptions on how much the energy use is reduced we estimate a potential of nearly 10 % reduction of the total energy use over a 10-year period. This is equivalent to a reduction of 3 TWh per year in a total of 3.7 million square meters. The allocation between categories and age groups are given in the table below.

It is estimated that 15 percent of the total building stock will not be able to reach the energy efficiency criteria in the latest building code. These buildings will reach the level given by TEK87, unless it is relevant to look into heavy modifications of the load-bearing elements. Note that rehabilitation of an old building to the level of TEK87, causes an increased amount of energy use because the requirements from criteria related to indoor air quality will lead to increased amounts of air flow.

For areas that implement a full rehabilitation the level is raised to TEK10-level. Quantitatively, this amounts to 51.3 per cent of the total identified potential. For areas where less comprehensive measures are implemented the difference between the current level of delivered energy and TEK10-level is reduced with 50 percent. Quantitatively, this amounts to 46.3 per cent of the total identified potential.

In addition to estimating the exact reduction in energy use per square meter the largest uncertainty lies in the estimated rehabilitation rate, especially related to situations where it is carried out less extensive rehabilitation. On the basis of Enova's own project portfolio, there is reason to believe that the activity that includes measures to improve energy performance is greater than estimates used in the table above. A higher rehabilitation rate is a strong contributor to raising the realistic energy efficiency potential.

Since it is less demanding to implement simple measures than more extensive renovations, there is probably room for increased potential associated with this. The possibilities for increasing the real potential are therefore likely to be found in the intersection between increased knowledge of the benefits from energy efficiency and increased rate of maintenance and rehabilitation work.

References

[1] Laustsen, J. (2008): *Energy Efficiency Requirements in Building Codes*, Energy Efficiency Policies for New Buildings, IEA Information paper.

[2] KRD (2010): *KRDs arbeidsgruppe for energieffektivisering av bygg*. Norwegian Ministry of Local Government and Regional Development

[3] NVE (2011): *Energibruk I Fastlands-Norge*. Norwegian Water Resources and Energy Directorate, Report 9/2011.

[4] Rogers, E. (1962): *Diffusion of Innovations*. Glencoe: Free Press.

[5] Sintef (2009): *Kriterier for passivhus og lavenergibygg – yrkesbygg*. Prosjektrapport 42:2009

“Bridging the gap” - a tool for energy auditing that encompasses both asset and operational parameters Use

Author Dr. A. J. Lewry, CEng, MIMM, CEnv, SOE; Mr. J. Ortiz; EurIng, MASHRAE, MCIBSE; Dr. A. Nabil; Mr A. Johnson, CEng, MCIBSE; Mr. S. Hussain, and Dr. P. Davidson, FInstP, FEI.

Abstract

To truly understand how a building uses energy you need to know something about the building itself and about how it is used. In current parlance, that requires both an Asset and an Operational energy rating. An asset rating models the theoretical, as designed, energy efficiency of a particular building, based on the intrinsic performance potential of the building envelope (the fabric) and its services (such as heating, ventilation and lighting).The higher the numeric rating, the worse the building is, and the greater the opportunity to reduce carbon emissions by improving the building itself. However, the asset rating provides no information about how the building is operated in practice.

The operational rating records the actual energy use from a building over the course of a year, and benchmarks it against buildings of similar type. Factors other than building quality, such as unregulated loads (e.g. IT, plug-in appliances) or building user behavior also create emissions, which are reflected in the operational rating.

This paper discussed the underlying principles of how tools were designed and how they bridge the gap between the two ratings to provide a more complete picture of how energy is used in a building.

Introduction

The rising cost of energy in the UK since 2000 has highlighted the need for improved management of Energy. The Department of Energy and Climate Change (DECC) updates its predictions of fossil fuel prices annually [1]. For example DECC’s modeling of gas prices based on four scenarios - the worst of these scenarios predicts a 100% increase in prices over the 10 years from 2008 [2].

As well as rising prices, security of energy supply has also become an issue, particularly since the UK changed from being a net exporter of gas to being a net importer in 2004. UK production satisfied only about 70% of our demand in 2010 [3].

This loss of capacity has led to increasing concern over energy security, as reported in an article in *The Guardian* in January 2010 [4].

When managing energy one has to overcome the false perception that it is a fixed cost to business and can be reduced only by tariff negotiation. Considering energy as a variable cost to a business provides the opportunity to discover the size of the potential savings.

Finally, there is legislation to comply with, examples of which are the Climate Change Levy (CCL), Climate Change Agreements (CCAs) with DECC and Industrial Emissions Directive [5], legislation and Environmental Permitting Regulations [6] which mainly cover industrial and manufacturing organisations.

These, along with the carbon reduction commitment (CRC) energy efficiency scheme, are initiatives designed to help meet the government’s carbon reduction targets, to which energy efficiency is a major contributor.

This all indicates the need for energy management as highlighted in a recent review of best practice [7]. The review pointed out that establishing the facts and having a systematic approach to data collection and analysis was essential for good energy management. As part of this exercise both an asset and operational rating were needed to truly understand how a building uses energy.

There is significant confusion in the non-domestic property market between the two different building energy ratings currently in use. The legal requirement for the UK commercial sector is for a calculated Energy Performance Certificate (EPC) which provides an intrinsic Asset Rating. All public buildings have to display a Display Energy Certificate (DEC), which is an Operational Rating based on measured energy use. There is pressure to extend DECs into the commercial sector - initially on a voluntary basis. The two ratings measure different things - and each has its value. What is missing is a means of relating one to the other.

Asset and Operational ratings

The asset rating is a measure of building quality: the higher the rating the worse the building is, and the greater the opportunity to reduce carbon emissions and improve the building itself. However, the asset rating provides no information about how the building is operated in practice. The operational rating records the actual energy use in a building over the course of a year, and benchmarks it against buildings of similar type. An asset rating models the theoretical, as-designed energy efficiency of a particular building, based on the performance of the building envelope (the fabric) and its building services strategy (such as heating, ventilation and lighting). Therefore, to understand and manage the energy use in a building, both ratings are required as they show different aspects of a building's total energy performance.

The building quality (provided by the asset rating) has a large impact on the total emissions, but does not explain all emissions. Other factors such as unregulated loads (e.g. IT, plug-in appliances) or building user behavior also create emissions, which are reflected in the operational rating.

Two offices built to the same specifications with the same asset rating could have very different operational ratings – a building with a low rating is used well by its occupants, a building with a high rating is used badly. In the latter, measures to change the behavior of the end users will be the best option for reducing energy use and carbon emissions.

An example of an asset rating is an EPC, as produced for buildings in the UK. One of the software tools used to create an EPC is the Simplified Building Energy Model (SBEM).This was produced by BRE in 2006 for the

Department for Communities and Local Government (DCLG) in England and Wales as a mechanism for calculating the energy used by buildings, and forms part of the department's process for implementing the EU's Energy Performance of Buildings Directive [8]. An EPC can be generated using the tool iSBEM, the free downloadable user interface for SBEM (www.2010ncm.bre.co.uk.) that was also developed by BRE for DCLG.

The asset rating is intended to inform people on first occupancy, i.e. at the point of construction, sale or rent, in order to help purchasers or tenants in selecting the right building. At this point in time, any previous metered information is not very helpful as the previous occupants' operation of the building, unregulated energy use, etc. could be quite different to that of the new occupants.

An example of an operational rating is a Display Energy Certificate (DEC) that is required in the UK by all larger public buildings. The Operational Rating Calculation (ORCalc) is the software used to calculate the operational rating of a building from annual utility consumption using current benchmarks to produce the DEC and an advisory report.

BRE's Building Energy Modeling team has identified a possible solution to the problem of linking the two rating methods, which has been rolled out as an Audit tool - *the Mauritian Building Energy Audit Tool (MBEAT).* This tool is able to join the two ratings together for the purpose of an Energy Audit.

In parallel, members of the team are also using some of the same underpinning calculation methods to develop the Green Deal assessment tool for non-domestic buildings for the Department for Energy and Climate Change (DECC).

The Mauritian Building Energy Audit Tool (MBEAT)

The United Nations Development Programme (UNDP) through the Global Environment Facility (GEF) has commissioned this project under which BRE has adapted the UK's NCM and SBEM into the energy auditing methodology and the Mauritius Building Energy Audit Tool (MBEAT), an energy auditing software tool for non-domestic buildings in the Republic of Mauritius.

The MBEAT tool comprises a calculation engine with a user interface. The purpose of MBEAT and its interface is to produce consistent and reliable evaluations of energy use in non-domestic buildings for energy auditing purposes. Although it may assist the design process, it is not primarily a design tool and should **not** be used for making strategic design decisions.

MBEAT consists of a calculation methodology (which runs together with an Energy Audit generator (EAgenMA) which utilises some of the same data during the calculation. The user sees the interface software, which interweaves these components together and interacts with a series of databases to provide consistent data to the calculation while simplifying the user's need to obtain raw building construction data.

Defining the Asset in MBEAT

When comparing the Asset and its operation performance one must first define the building. There are a number of stages to inputting a building in MBEAT:

- a Enter general information about the building, the owner, and the energy auditor, and select the appropriate weather data.
- b Build up a database of the different forms of constructions and glazing types used in the fabric of the building.
- c After "zoning" the building (on the drawings), create the zones in the interface, and enter their basic dimensions, along with the air permeability of the space.
- d Define the envelopes of each zone, i.e., walls, floor, ceiling, etc. The envelopes' areas, orientations, the conditions of the adjacent spaces, and the constructions used all need to be defined.
- e Within each envelope element, there may be windows/rooflights or doors. The areas and types of glazing or door within each envelope element need to be entered.
- f Define the HVAC (heating, ventilation, and air conditioning) systems, the HWS (hot water systems), and any SES (solar energy systems), PVS (photovoltaic systems), wind generators, or CHP (combined heat and power) generators used in the building.
- g Define the lighting system and local ventilation characteristics of each zone, and assign the zones to the appropriate HVAC system and HWS.
- h Run the calculation and assess energy performance.

MBEAT calculates the energy demands of each space in the building according to the activity within it. Different activities may have different temperatures, operating periods, lighting standards, etc. MBEAT calculates heating and cooling energy demands by carrying out an energy balance based on monthly average weather conditions. This is combined with information about system efficiencies in order to determine the energy consumption. The energy used for lighting and hot water is also calculated.

Defining a poorly managed asset

MBEAT compares and adjusts both the asset and operation energy usage of a building. However, in order to adjust the asset energy usage, one must first address the issue of the Poorly Energy Managed Building (PEMB) definition.

The Poorly Energy Managed Building (PEMB) definition

The PEMB is needed to calculate one end of a scale between well managed (equivalent to the asset energy usage, where the building is perfectly controlled to the requirements of the activity databases) and poorly managed (where the activity database parameters are not adhered to). A separate scoring exercise places the actual building on this scale, which is transposed from the calculated to an "actual" scale. The position on the scale indicates where the metered performance is expected to be, and hence the theoretical split between asset and operational performance can be transposed onto the actual scale, and theoretical predictions about the impact of improvements can also be transposed to the actual scale.

How might the activity database parameters be degraded?

If a zone is not controlled to the "ideal" set points and timings in the database for the activity in that space, it can be regarded as inadequately managed. Alternatively, some parameters might change as a result of overloading rather than mismanagement. The question is: how far might they be expected to drift before the zone and building can be considered "poorly" managed? And in which direction might they drift?

1. The amount of change that constitutes poor management, or results from some issue, over which the energy manager has no control, has to be a judgment based on what could reasonably be expected in the situation.
2. The direction we are concerned with is that which causes energy consumption to rise.

Defining and quantifying energy management within the asset

The definition of the PEMB allows the sliding scale to the well managed building to be calibrated. However, the extent of the energy management within the building needs now to be defined and quantified so that it can be positioned on this scale.

As a starting point the authors looked at a tool developed for The Energy Efficiency Best Practice programme, in the 90's – "*Energy management priorities - a self-assessment tool*" [9]. This tool uses **Energy management matrices** which are performance based and are underpinned using detailed matrices covering all the technologies within the built environment within the UK.

The weakness of these matrices is that they give an equal weighting to each of the energy management issues and technologies considered. In addition, there is a need to identify any new parameters which are particular to the built environment of the climatic zone being considered and filter out those which are not relevant. An example of this is that MBEAT considers the effect of white roofs but heating and its associated controls are not.

The production of a series of new matrices with weighted scores was initially carried out through a series of information and data gathering exercises which engaged the building professionals in Mauritius. This was then tailored by producing an energy management tool which dovetailed to the asset tool.

The Energy Management tool

The energy management tool, which is contained within a locked excel workbook, calculates an energy management score. The tool contains a number of worksheets which address all the energy management issues .This score is calculated on the basis of the data collected by the auditor from the real building.

Matrix 1: Use of Controls					
Building:	0 (*Enter name on summary scores sheet*)				
Topic	Use of Controls				
Subject	Central plant level controls				
Question	Location of controls	Operating times	Time response to day to day changes	Central plant temperature settings	Energy manager understanding
Score	1				
4	BEMS with trained personnel to operate it	Different schedules for each day	Optimum start and stop depending on internal temperature performance on previous day	Cold set points adjusted to allow highest evaporating temperature and hence highest COP consistent with providing cooling needs based on exterior weather conditions	Rigorous checking of controls function, settings, and system balance carried out once per year. Documented procedures and comprehensive records of results.
3	Computer-based building energy management system (BEMS)	Set to exactly normal occupancy	Optimum start (only) depending on internal temperature performance on previous day	Cold set points adjusted depending on differing dehumidification requirements based on exterior weather conditions	Full checking of controls function, controls, settings, and system balance carried out once per year. Documented procedures exist for each check. Some results on record.
2	Central control panel from which time, temperature etc settings can be adjusted	Turned on/off by staff	Time switch with seasonal differences	No central chiller plant	Informal checking of controls function and system balance carried out once per year. Schedule of checks exists but no proof of occupancy
1	Controls dispersed around building	More hours than normal occupancy	Time switch only	No changes (eg evaporator or chilled water temperatures as set by manufacturer)	Annual functional checks carried out although these are not well documented.
0	Don't know where controls are OR There are no controls	No control (enabled constantly)	No response to changes	Don't know what settings are OR what you mean by this	Maintenance is on breakdown basis and controls are checked only when things go wrong.
Weighting for relevance to calculation	1	3	2	1	3
Overall Score	1	0	0	0	0
Enter scores on red row above, not here					
Total score	1				
Total possible score	40				

Figure 1: Screen shot of Central plant level controls matrix

In order to populate the tool, the auditor must answer each of questions with a score between 0 and 4 depending on the level of management within the building as determined by the energy survey of the building and its occupants. The score must be a whole number (i.e. 0, 1, 2, 3 or 4) - it cannot be a fraction or a decimal. Also, the auditor must choose the lowest common denominator, e.g., if a building has a central control panel (scores 2) which controls the majority of the building but the rest of the building has the controls dispersed around (scores 1), the auditor must choose the lowest common denominator which is 1 and enter this against the Question - ***Location of controls*** – see Figure 1. If there is insufficient information to completely answer a question, the auditor must enter a zero score. The reason for using such a dictatorial approach to ensure consistency in the calculation, this is essential if buildings are to be compared.

Once the score is entered, the worksheet multiplies this score by a weighting. In this case, it is one so the overall score for that question is 1 (score) x 1 (weighting) =1. This is done for each of questions within the worksheet, which then gives a total score for the area of **Use of controls: Central plant level controls**. The worksheet also shows the highest total possible score for this matrix which in this case is 40.

This exercise is carried out for each of the six matrices and the workbook then sums these together to give a final score for the building out of 228. The summary worksheet captures these scores and then normalises the final score to one with a range between 0-100 (see Figure 2).

Matrices	Building:	Summary Score	Total possible score
Matrix 1: Use of Controls		0	40
Matrix 2: Use of Controls - Local (zone level) comfort controls		0	40
Matrix 3: Use of Controls - Lighting		0	36
Matrix 4: Quality of maintenance - Building		0	40
Matrix 5: Quality of maintenance - HVAC plant & Lighting		0	40
Matrix 6: Motivation - Occupants & Management		0	32
Final score		0	228
Normalised Energy Management Score for MBEAT		0	

Figure 2: Screen shot of the summary scores worksheet

Operational data and the MBEAT tool

As well as the energy management score obtained from the worksheet, meter data also needs to be entered. The metered data needs to be of a full year so that any seasonal variations are ironed out and each of the fuels types used within the building is entered separately in the tool.

Once the metered data has been entered so can the energy management score based upon the audit. This score is entered into the MBEAT tool with the model in Asset energy mode (Audit type set to “Assessment of current performance” see Figure 3).

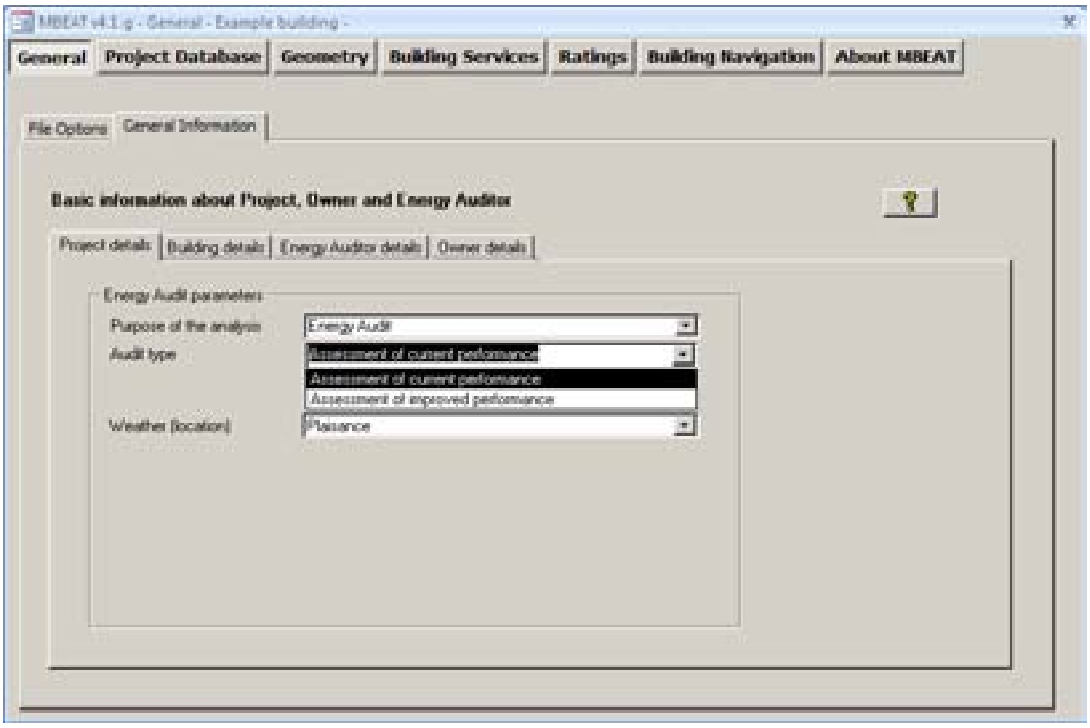


Figure 3: Screen shot of MBEAT Project Details sub-tab

The normalised management score of between 0 and 100 is entered in the current field in the management scores within the *Building Services* form, see Figure 4.

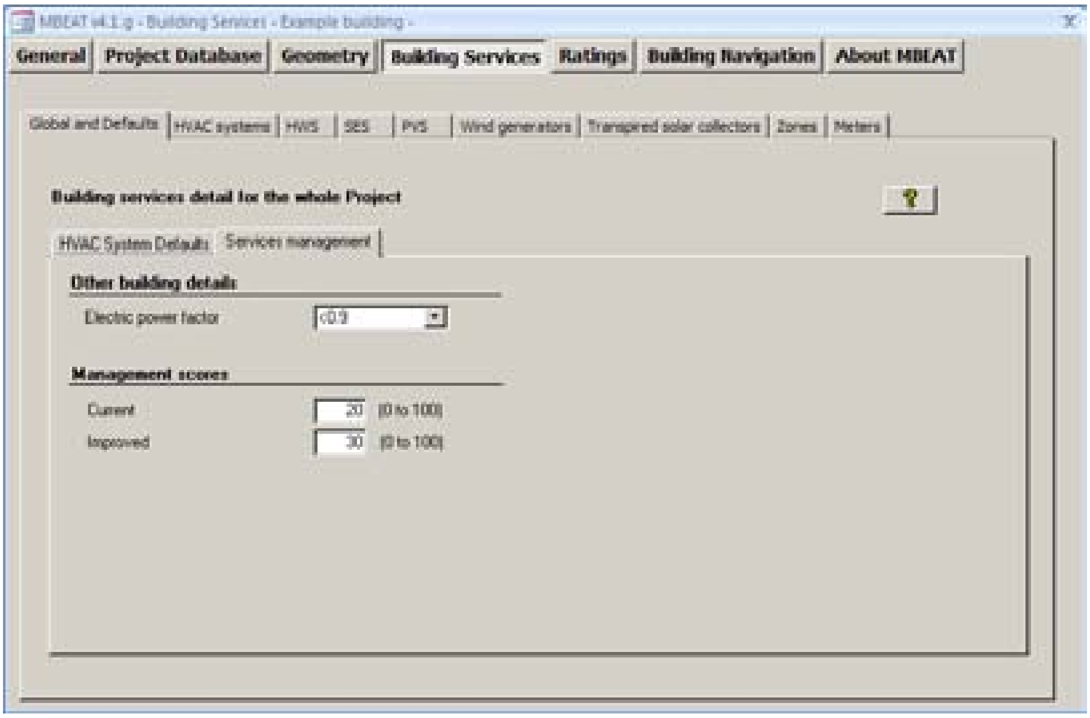


Figure 4: Screen shot of MBEAT Services Management sub-tab

The auditor must first run it in Asset energy mode (Assessment of current performance mode), because the tool generates a secondary file in this mode which is essential to any further analysis. Once this model is generated and saved the auditor can consider how the operation of the building can be improved.

How improved operational performance is assessed

At this point, the auditor needs to consider how the management score could be improved. Whilst carrying out the energy survey of building and its occupants, the auditor should have recorded initial ideas of how each score within each matrix could be improved and therefore tailored the recommendations report accordingly. The auditor will now have to run the model with MBEAT in Audit energy mode (Assessment of improved performance mode) – see Figure 3. Before this can be done the auditor will have then identified those operational recommendations that could be removed, removed them and added a reason for the audit trail. At the same time, the auditor re-visits the energy management tool and re-enters the scores based upon their suggested improvements. The spreadsheet tool recalculates the final score for the building and this new improved score of between 0 and 100 is entered in the improved field in the management scores within the *Building Services* form shown in Figure 4. It should be pointed out that the Energy Management tool and MBEAT will only give an indication of possible savings and feasibility studies may be required.

MBEAT calculations and outputs

The MBEAT tool calculates the asset rating using the standard activities and weather file contained within the tool. Using the metered data and initial energy management score entered by the auditor it then calculates a Transposed Asset and adjusted Operational performance using this data to correct for actual patterns of usage and microclimate.

Once the Asset and Operational performance is calculated, MBEAT then uses the improved energy management score to determine the:

a. **The potential operational saving** for the building if management improvements were applied based on the energy performance of the building that corresponds to the current and improved management scores as input by the energy auditor.
b. **The potential asset saving** if asset improvements were applied to the building, based on the energy performance of the current and improved building models as input by the energy auditor.

The mechanics of these calculations in MBEAT can be seen in Figure 5.

The resulting MBEAT outputs are shown in Figure 6, where the example building in question has all the potential savings as operational, indicating this is where investment should be targeted. However, at this stage it should be remembered that operational savings relate to how the building is run and not the quality of the asset.

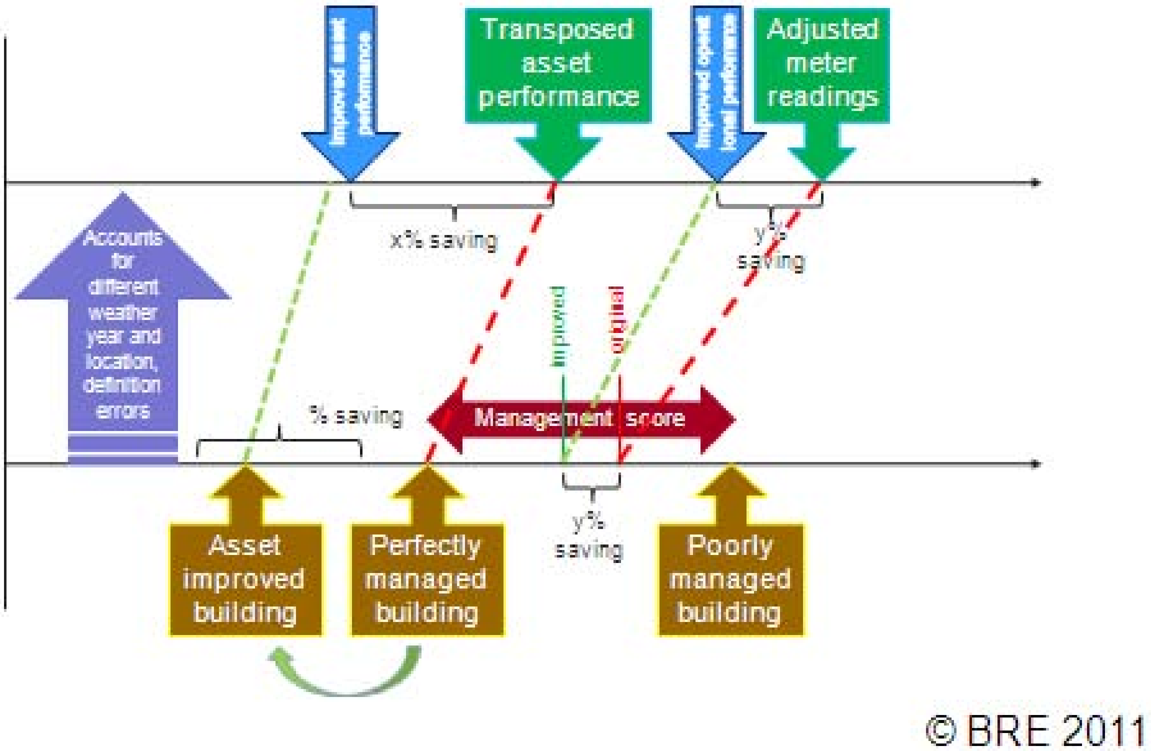


Figure 5: Details of the MBEAT calculations

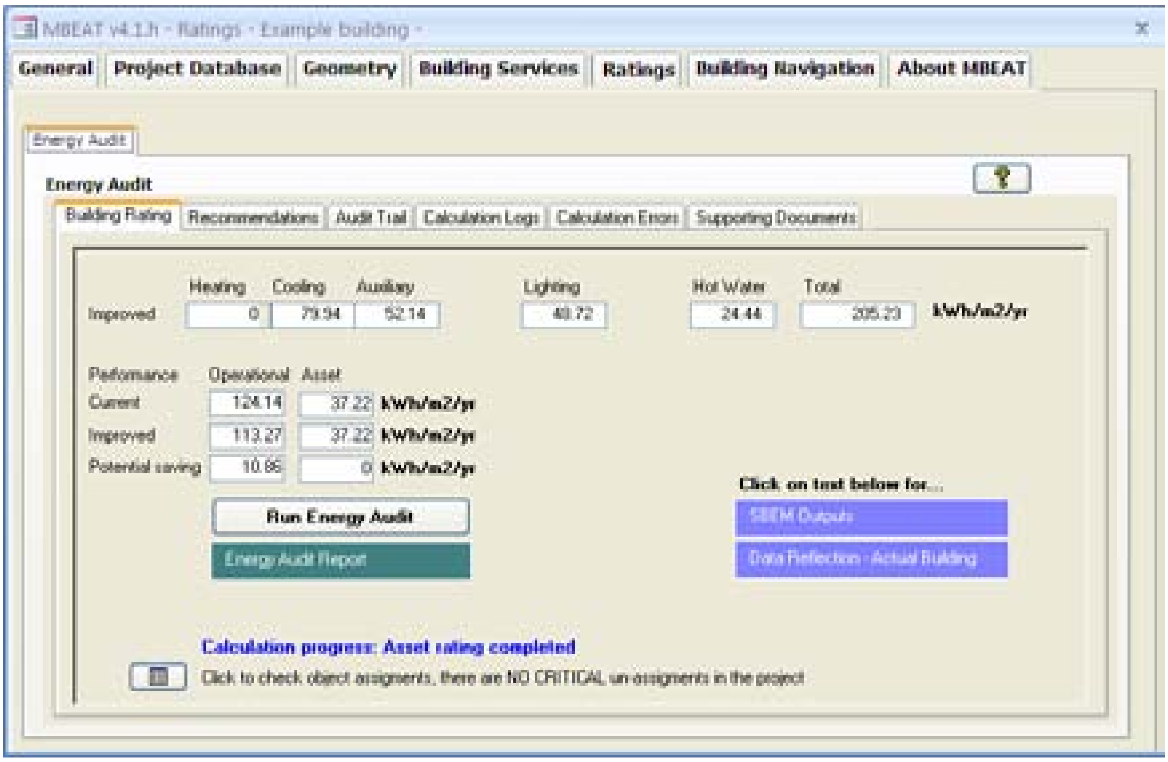


Figure 6: Screen shot of MBEAT ratings Tab

MBEAT suitability and adaptability

The calculation procedure implemented in MBEAT is suitable for use with the majority of buildings, but some designs will contain features that mean that more accurate energy calculations may be obtained by more sophisticated calculation methods.

All calculation processes involve some approximations and compromises, and MBEAT is no exception. The most obvious limitations relate to the use of the CEN monthly heat balance method. This means that processes which vary non-linearly at shorter time-steps have to be approximated or represented by monthly parameters. The HVAC system efficiencies are an example of this. On the other hand, MBEAT does have provision to account for processes that may not be present in software packages that contain more sophisticated fabric heat flow algorithms, such as duct leakage and infiltration allowances.

It is, therefore, difficult to give absolute rules about when MBEAT can and cannot be used. As broad guidance, it is more likely to be difficult to use MBEAT satisfactorily if the building and its systems have features that are

(a) not already included in MBEAT; and
(b) have properties that vary non-linearly over periods of the order of an hour.

However, as the example above shows, this is not a universal rule. There is a balance between the time and effort required to carry out parametric studies to establish input values for MBEAT and detailed explicit modeling of a particular building.

Features which cannot currently be represented in MBEAT:

- Ventilation with enhanced thermal coupling to structure.
- Light transfer within a building, for e.g., through highly glazed internal surfaces between atria and surrounding spaces.

Although MBEAT has been designed to be used within the construction types, practices, activities and climate of Mauritius the tool can be adapted to any other country and/or climate.
However to do these, data specific to that built environment and climate is needed to produce the databases underpinning the tool. This data has to be collected, collated and verified to populate the following databases:

(a) Climatic data for the areas to be considered;
(b) Activity types and schedules so that the occupancy patterns can be modeled;
(c) Construction - types and properties of the building elements such as walls, their thickness and associated U-values;
(d) Services – types of plant (including lighting) and the efficiencies.

In addition, the important Energy Management Issues need to be captured in order to populate the matrices. Alongside this each issue needs to be ranked and weighted to that a quantifiable Energy Management score can be produced.

Conclusions and recommendations

Despite its limitations, MBEAT does provide a fledgling methodology for linking the Asset and Operational performance of a building and thus bridging the gap between the two measures. The result is a more holistic view of building performance and a tool that allows possible savings to be quantified with more confidence and improvements to be prioritised.

The approach described will help to understand and improve the comparison between existing (asset and/or operational) approaches. Evidence from the initial use of the MBEAT tool in Mauritius, indicates that the underpinning methodology allows the asset and operational performance of a building to be compared for the purpose of highlighting where investment should be targeted.

As more buildings are audited and modeled, the accuracy of operational ratings could be improved by further analysis of the data. There is further scope for the refinement of the “energy management standard” but this should be done based on the observations of the energy auditors and not by manipulation of the energy consumption data.

With the introduction of the Green Deal tool there is an opportunity for such research to be carried out in UK. Our use of EPCs is in the mature stage and reconciliation with the operational performance should be a future aim of research supported by Government and others.

References

[1] Department of Energy and Climate Change (DECC). Communication on DECC fossil fuel price assumptions. Available at: www.bis.gov.uk/files/file51365.pdf

[2] Lewry A J. Literature review on the use of forecasted energy and water prices in construction projects. SCI-Network Report 4.2. London, SCI-Network, 2011. Available at: www.sci-network.eu/resources/reports

[3] Department of Trade and Industry (DTI). JESS: long-term security of energy supply. London, DTI, 2006.

[4] Macalister T. Energy security questioned as National Grid cuts off gas to factories. The Guardian, 7 January 2010. Available at: http://www.guardian.co.uk/business/2010/jan/07/gas-rationing-national-grid-factories

[5] Directive 2010/75/EU. Directive on industrial emissions. Brussels, European Parliament and Council of the European Union, 24 November 2010

[6] The Environmental Permitting (England and Wales) Regulations 2010. SI 675. London, TSO, 2010.

[7] Lewry A J. Energy Management in the Built Environment – A review of best practice. BRE FB 44. Bracknell, IHS BRE Press, 2012.

[8] Johnson T. SBEM for non-domestic buildings: an introduction. BRE IP 7/10. Bracknell, IHS BRE Press, 2010.

[9] UK Government's Energy Efficiency Best Practice Programme, Energy management priorities - a self-assessment tool (GPG306), 2001 – currently available from the Carbon Trust (www.carbontrust.co.uk/publications/pages/home.aspx).

Evaluating and modelling nearly-zero energy buildings; are we ready for 2018?

J.J. Bloem[1], P. Strachan[2]
[1] European Commission, DG JRC Institute for Energy and Transport
[2] ESRU, University of Strathclyde, Glasgow, UK

Abstract
With the recently reviewed Energy Performance of Buildings Directive [2010/31/EU] the need for up-to-date design tools and simulation techniques is evident. To optimise the design and to reduce energy consumption in the building sector the energy calculation techniques have to deal with dynamic processes with a diversity of time constants (hourly, daily, monthly and seasonal). In relation to new building design, the need for integration of renewable energy technologies in these low energy buildings is obvious. Solar energy (passive and active) technologies in the built environment will become commonplace, including passive design and more importantly solar heat. This requires the ability to analyse options for nearly-zero energy building design in the energy system of the future. This paper aims to assess the state-of-the-art of evaluation and modelling methods and tools for nearly-zero energy buildings: what is required and how to achieve it? And it discusses the question: "How reliable are simulation methods in predicting the energy consumption?" The paper will support the development of a strategy for low energy building design in relation to EU Energy Policy (e.g. Directives such as EPBD, EESD, RESD and RED) and EU legislation (such as EU energy standards) that have recently been reviewed.

Keywords: Energy modelling, NZEB, EPBD, CEN standards

Background
The Energy Performance of Buildings Directive (EPBD) 2010/31/EU (recast) was adopted by the EU Council and the European Parliament on 19 May 2010. It requires that from the year 2020 onwards all new buildings will have to be 'nearly zero energy buildings' and comply with high energy-performance standards and supply a significant share of their energy requirements from renewable sources. For public buildings these standards need to be met by the end of 2018. This will require the development of new design approaches focused more on the energy flows in buildings [1]. The trend for energy consumption in buildings is a decrease of thermal energy for space heating and an increase of electricity for installations and appliances [2]. In addition to improved new building design, a more dynamic and intelligent local energy management is required that takes into consideration local climate, distributed energy supply and demand and interaction with the grid. Major renovation is seen as an important focus for reducing energy consumption. The integration of renewable energy technologies in the built environment will be essential for reducing final energy consumption and in particular the reduction of GHG emission.

The EPBD and its recent recast are demanding more from simulation calculation programs. Building dynamics [3] are important, particularly in low energy buildings which have variable demands for heating, cooling, hot water and power, and where significant intermittency and variability of supply exists (passive and active solar, air source heat pumps etc). In addition, new buildings (nZEB) and major renovation projects require a cost optimal calculation (as in the EPBD delegated act (June 2011). The building will have a more important role in an integrated future energy infrastructure and the methods to assess appropriate technologies that are energy and cost efficient is urgently required.

Nearly-Zero Energy Buildings
Building simulation software tools will become a very important part to the contribution of the success of the EPBD in relation to the reduction of energy in the building sector. In relation to

energy consumption it is important to define what the boundaries are for a building or building environment. Atanasiu et al. [4] presents principles for nZEB and discusses the definition problem. Also REHVA questions how the definition of nZEB can be made in a harmonised way [5]. Apart from the calculation method itself one needs to know what the boundaries are and how to calculate the energy consumption of a particular building, group of buildings, or community. This requires consideration of renewable energy technologies, the dynamic nature of the building energy flows and occupancy behaviour.

Buildings are the most obvious elements of urban design - they shape and articulate space in the city. Well designed buildings and groups of buildings work together to create a sense of place. Transport systems connect the parts of cities and help shape them, and enable movement throughout the city. The balance of these various transport systems with the group of buildings is what helps to define the quality and character of cities. Therefore urban designers have to deal with the energy infrastructure also (http://www.urbandesign.org/).

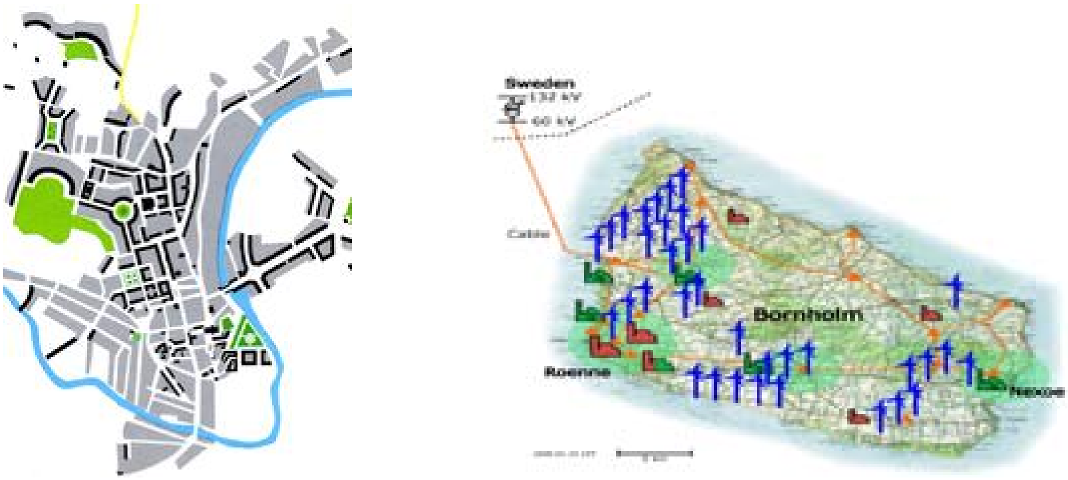


Figure 1. Urban dimension for energy infrastructure; City and Island

Buildings will form a key element in the energy system (infrastructure) of the future (2020 and beyond). Further research and demonstration is needed to develop approaches to analyse the optimum configurations, with the building acting as a consumer and as a part of the distribution system.

A philosophy for energy reduction in the built environment should include the methodological approach as well.

- Reduce energy consumption (by improving the envelope insulation)
- Improve energy efficiency (building installations and apparatus)
- Increase use of renewable energy technologies in the built environment
- In relation to primary energy consumption: maximize the energetic use of fossil fuels.

This approach will lead to low energy consumption but more prominent dynamic impact and uncertainty from occupancy behaviour. To optimise the design and to reduce energy consumption in the building sector the energy calculation techniques have to deal with dynamic processes with a diversity of time constants (hourly, daily, monthly and seasonal). In relation to new building design, the integration of renewable energy in these low energy buildings is needed. Solar energy technologies (passive and active - not only PV electricity) in the built environment will play a prominent role, particularly in passive solar design and solar heating systems.

In general one may note that the trend is a shift in energy carrier, with electricity forming a greater proportion of building energy use. The overall energy demand is only decreasing slowly, with the decreased demand for thermal energy (due to improved insulation and greater air tightness) balanced by an increase in electricity (for appliances and equipment). In addition the variable nature of supply implies the need for improved communication with energy providers and local energy management for balancing the energy demand with supply and storage. Dynamic evaluation techniques together with smart grid environments will provide the necessary information for utilities and energy consumers. This has consequences for building designers in particular who are charged with analysing optimum energy solutions.

Integration of sustainable technologies (energy, construction, appliances, etc.) in the energy distribution network will be a complex process. This concerns the integration of variable resources, such as wind and solar electricity, in a highly sophisticated way using up-to-date information technology and distributed demand/supply management through the buildings network. Storage techniques for electricity (batteries) will emerge when buildings consume less thermal energy but more electrical energy. This will increase further with higher market penetration of heat pumps that need higher electricity intensity from the energy infrastructure.

Passive design is important for minimising energy consumption, through improved insulation of windows, walls, roofs and new construction techniques avoiding thermal bridges and improving airtightness. However the building stock is renewing too slowly in order to bring the overall energy consumption in buildings down to desired levels. The development in the construction market [EUROSTAT, 2010] reflects the impact of the economic and financial crisis, the oversupply of construction and reduced confidence, see Figure 2. The building energy related industry is directly affected by this development; however it will challenge the development and marketing of innovative building products supported by the EPBD.

The relation between a nearly-Zero Energy Building or a complex of buildings and the energy infrastructure has to be assessed based on the balance optimisation of demand, supply and storage and that requires a more dynamic methodology, taking also into account the thermal mass.

Figure 2. Development of the production index in the construction sector. (Source: Eurostat 2010)

Two important energy Directives, the recast of the EPBD and the Energy End-use Efficiency and Energy Services Directive, should give a new impetus to an increase of energy savings and energy efficiency in order to reach the targets set by the EU for 2020. At present, a 9% saving is expected, well below the target of 20%. Problems with the implementation of the Directives into national regulations (and in relation to European standards) are seen as an additional barrier.

Hesitant investment in the implementation of energy efficient measures is considered as a barrier also. Confidence has to return in the financial and economic markets to stimulate the construction industry and the associated investment in the energy related markets.

CEN energy standards

The main current European standard EN ISO 13790 for the calculation of energy use for space heating and cooling [6], has been embedded for compliance and certification procedures in most EU countries. However, as acknowledged in a recent evaluation of the standard and its implementation [8, Staudt et al 2010], most passive systems are not explicitly covered in the CEN-standard and many technologies are missing (e.g. night ventilation, double skin facades, ground-coupled heat pumps, moveable blinds). It is likely that additional correction factors can be included for some of these technologies and this may be acceptable for compliance checking. To provide continuity for building energy compliance and certification, it is unlikely that there will be a radically different calculation procedure in the near future, although perhaps an hourly calculation method rather than monthly may be more prominent. For selection of the most appropriate low energy design, a more detailed method is needed.

Standards may request industry to provide more specific technical information that is necessary for dynamic simulation, so that a more complete performance map is available rather than limited data at nominal steady state conditions. Some technologies, such as heat pumps and solar technologies, are more dynamic and variable than the present calculation methodology takes into account. The dynamic energy flows due to occupancy behaviour are rather invisible in the present set of energy standards.

Dynamic thermal modelling is explicitly allowed in EN ISO 13790 and many national implementations. In principle such programs can be used to investigate options for low energy design as they are, for the most part, able to model the detailed dynamic interactions of passive and active technologies with the building and prevailing climate. They will therefore play a more important role in future design and compliance checking - as in the case of LEED certification in the USA, for example [7]. However, such programs are not configured for easy comparison of a range of low energy technologies (energy supply, demand and storage for both thermal and electrical forms of energy; new and renewable energy technologies; innovative building products and control for improved performance). A new approach is needed with the focus on energy performance together with a comprehensive set of tests (derived from testing and benchmarks) to ensure the modelling predictions reflect real energy performance.

Building simulation software; State of the Art

The need for up-to-date design tools and simulation techniques is evident. At present most simulation tools are modular and start from the building, its components and systems perspective. Another approach and probably necessary path to go is starting from the holistic energy flow perspective.

The state of the art can be addressed in several questions such as:

- "How reliable are simulation methods in predicting the primary and final energy consumption?"
  When insulation levels increase and ventilation improves through heat recovery, the impact on prediction from variable gains becomes more important. This requires a more dynamic approach to assess all energy flows, in particular the on-site produced energy, such as from PV. There is also a marked lack of good quality monitored data that is suitable for validating the calculation methods.

- "Is current simulation software able to perform as well when electrical energy consumption increases to 50%?"
  Traditional building simulation techniques are based on heating / cooling demand and management while the trend is an increase in electricity consumption. This important part is not always covered by energy simulation software – it requires improvements to the simulation programs as well as detailed monitored data on electrical supply and demand profiles.

Integration of renewable energy.

The integration of RE in the electricity infrastructure requires often direct consumption or storage which is not always available. Balancing between supply and demand including the available storage in the built environment could improve this situation. In particular for electricity the grid in some occasions can not absorb the production and utilities are seeking for ways to deal with it. Solutions may become a matter of financial (energy delivery) contracts (earning money or saving energy) at other time scales than direct energy consumption.

The Danish EDISON project [9] on Bornholm Island studies the interaction between building and transport electricity consumption and how information technology could be used to optimize the balance between demand (buildings), supply (wind) and electric cars (storage) and the requirements for the energy market. In that context one may question up to what accuracy could be given to the prediction of energy consumption in buildings with the present simulation tools?

Occupancy behaviour

A variable aspect to energy consumption in buildings is covered by the rather unknown occupancy behaviour. This aspect becomes more important when building energy needs are reduced by improved insulation and more energy efficient apparatus and installations are used.

In the short term a top-down approach could give the boundaries for energy consumption related to occupancy behaviour. Identifying the characteristic parameters for specific building energy consumption from available measured data (smart metering) by identification techniques could support the optimization of energy balancing. In the longer term, bottom-up research should give more insight in important aspects related to occupancy behaviour in a wider urban related energy consumption context (including transport, living-work relationships). This includes more knowledge on daily energy flow patterns in buildings and community areas.

Conclusion

The building as an energy system should be considered in a much wider dimension (e.g an urban area) and adopted in new and revised EU standards. The integration of renewable energy technology requires a more dynamic calculation method based on balancing the demand, supply and storage issue. Improvements in the same direction could be made to simulation programs that allow a more energy-focused design approach. Such calculation tools for modelling based on dynamic methodology are required to support building and urban designers. The modelling work requires realistic data from test installations for innovative and energy complex building elements.

So to answer the question of the paper title, there is still much to be done before we can effectively design building-centred energy systems with highly variable supply, demand and storage.

References

[1] Bloem, H., Atanasiu, B., 2009. Dynamic analysis methodologies applied to energy management in residential buildings. In: EEDAL'09 Conference 16-18 June, Berlin, Germany.
[2] Bertoldi, P. Atanasiu, B., Electricity Consumption and Efficiency Trends in the Enlarged European Union. (2007) EUR 22753 EN
[3] "Whole Building Testing, Evaluation and Modelling for Energy Assessment". 18-19 May 2011, Copenhagen, Denmark.
[4] Atanasiu B., et al. Buildings Performance Institute Europe (BPIE), Belgium Principles for implementing nearly Zero-Energy Buildings in Europe, 2011.
[5] REHVA - How to define nearly net zero energy buildings nZEB (2011)
[6] EN ISO 13790 - Energy performance of buildings: Calculation of energy use for space heating and cooling
[7] LEED, US Green building Council, http://www.usgbc.org
[8] Staudt A, Erhorn H and van Dijk D, Report on the Application of CEN-standard EN ISO 13790: Energy performance of buildings: Calculation of energy use for space heating and cooling, CENSE project document CENSE_WP3.3_N03, May 2010.
[9] The EDISON project - Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks. http://www.edison-net.dk/

Energy Efficiency Potential and Policies of Commercial equipment

-Comparison with those of residential appliances-

Jungwook PARK, International Energy Agency

Michael McCann, Thinkwell Australia Pty Ltd

Abstract

Owing to its low levels of total energy consumption, the commercial sector[1] has received relatively little attention compared with the residential sector. However, **in terms of electricity consumption, the commercial sector plays a significant role**. IEA data show that from 1990 to 2009, electricity consumption in the commercial sector of OECD countries increased by 72.3% compared with only 47.7% in the residential sector. The share of commercial electricity consumption became on a par with the residential sector (33.4%) surpassing industry (32%), which had accounted for 41% in 1990. Analysis indicates that the potential of electricity savings by commercial equipment is huge. In some countries, such as the US, the potential of electricity savings for commercial equipment surpasses that of residential appliances. This is further reinforced by a benchmarking study which shows a larger potential of electricity savings that could be realised by Minimum Energy Performance Standard (MEPS) for commercial air conditioners (AC) compared to residential AC in Australia. However, energy efficiency policies for commercial equipment are not as well developed as those for residential appliances. Compared to residential appliances, there are additional barriers for developing measures targeting commercial equipment including heterogeneity of products and sub-sectors, limited availability of information, and lack of established objective and quantitative methods to measure the energy efficiency of commercial equipment. It is found that more active and strategic policies are required to realise the potential of electricity savings of commercial equipment since current energy efficiency policies for commercial equipment is not sufficiently developed and implemented.

1. Introduction

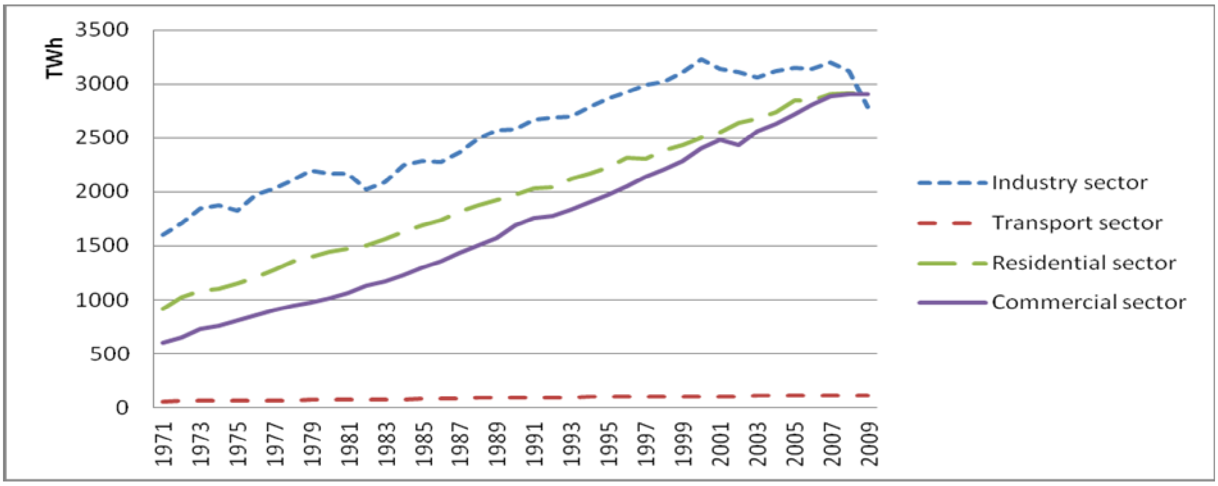
Energy efficiency is one of the most cost-effective ways to simultaneously address the challenges of energy security, economic growth and climate change. Improvement in energy efficiency delivers energy saving as well as a range of multiple socioeconomic benefits, which include health and well-being, energy affordability for low income households, increased asset values, avoided energy infrastructure investment, employment and industrial competitiveness. Energy efficiency also contributes to sustainable development and green growth. In terms of climate change mitigation, energy efficiency could play a crucial role in delivering around 50% of total required CO_2 abatement until 2035 according to the IEA 450 ppm scenario[2]. Energy efficiency is particularly important early in that period (it would have to account for 70% of the abatement by 2020) due to the longer lead-time of other measures such as the deployment of renewable energy. To realize this potential, energy efficiency policies and measures should be developed and implemented sufficiently in all sectors.

[1] Commercial is termed “tertiary sector” in the European Union, “commercial and Institutional sector” in Canada, “commercial and public service sector” in IEA databases.

[2] It aims to limit the long- term increase of mean global temperature to two degrees Celsius above pre-industrial levels

To date, most energy efficiency policies are developed and implemented for the industry, transport and residential sectors. The commercial sector has drawn relatively little attention from policy makers. One reason for this is that compared to other sectors, the total energy consumption of commercial sector is lower. But in terms of energy source, *e.g.* electricity, gas, coal and oil the growing importance of the commercial sector is apparent. In OECD countries, electricity consumption in the commercial sector is growing the fastest. According to IEA data, commercial electricity consumption increased by 72.3% compared with 47.7% growth in the residential sector, 23.2% in transport and 7.8% in industry from 1990 to 2009. The commercial sector accounts for 33.4% of total electricity use in 2009, compared to 26.6% in 1990. The share of electricity consumption in the commercial sector is the largest with the residential sector by overtaking industrial sector of 32%, which accounted for 41% in 1990.

Figure 1. Electricity consumption by sector in the OECD (1971-2009)



Source : IEA database

This indicates that it is essential to check whether energy efficiency polices for commercial equipment is sufficiently developed in order to fully realise the potential of electricity savings of the commercial sector.

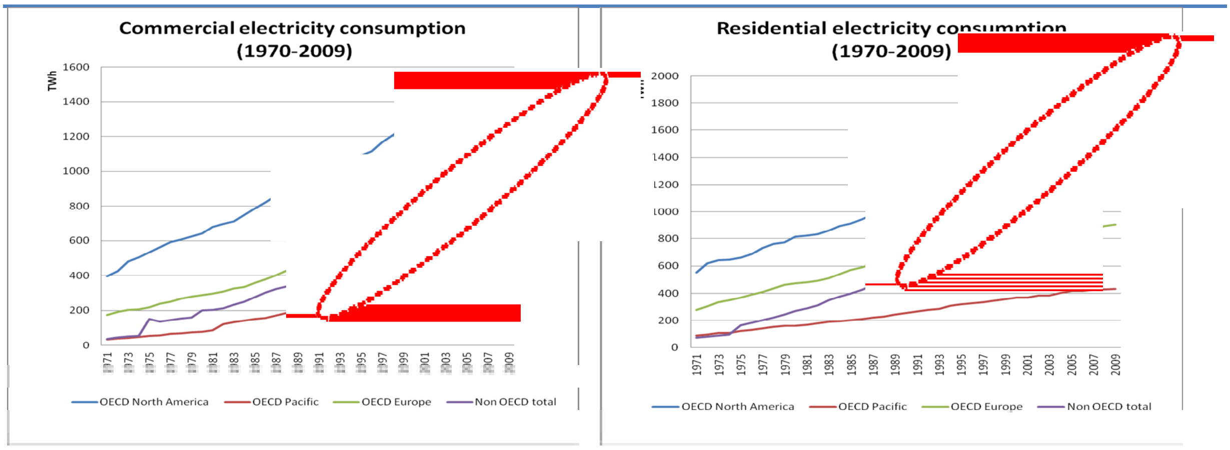
2. Methodology

The authors examine electricity consumption trends in the commercial sector by region and end-use to identify the main drivers of growth in electricity consumption. The energy efficiency policy instruments focused in this paper for appliances and equipment are standards and labels (EES&L). Drawing on the outcomes of existing studies, the authors compare the magnitude of potential of electricity savings of commercial equipment with that of residential appliances globally and in specific countries. Then a benchmarking study is carried out for commercial air conditioners (AC) in Australia where minimum energy performance standards (MEPS) is widely implemented for AC. Various energy efficiency barriers are examined followed by a review of energy efficiency policies for commercial equipment in major OECD countries with a focus on EES&L.

3. Electricity consumption trends in the commercial sector

Global trends of electricity consumption by region in commercial sector look very similar to residential sector. In the 1970s, North America was the largest electricity consumer in the residential sector followed by OECD Europe, OECD Pacific and non-OECD countries. However, the electricity consumption has since soared in non-OECD countries as their economies have developed. In the commercial sector, a similar pattern is expected where OECD countries have a stable growth rate of electricity consumption while that of non-OECD countries is increasing. While non-OECD country commercial sector consumed the least amount of electricity in the 1970s, currently non-OECD countries are already becoming the second largest consumers after North America (Figure 2). Commercial electricity consumption of non-OECD countries is forecast to soon overtake that of North America.

Figure 2. Electricity consumption trend in the commercial and residential sector



Source: IEA database.

Since the commercial sector is composed of heterogeneous sub-sectors like office buildings, schools, supermarkets, hotels, and universities etc, information on the commercial sector is quite limited compared to that of the residential sector. It is very difficult to access disaggregated data such as electricity consumption by end-use (heating, cooling, lighting, cooking, water heating, appliances etc) while disaggregated information on the residential sector is available in many countries. This paper is based on a review of United States, Japan, Canada, Korea and European Union (EU) for energy consumption mix of the commercial sector as well as the trend of commercial electricity consumption by end-use. Those countries accounted for 94% of commercial electricity consumption in OECD in 2009[3]. However, in the case of the EU, trend information is not available for commercial electricity consumption by end-use.

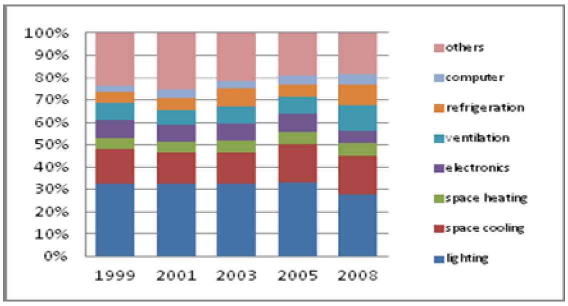
The main energy sources in commercial sector were oil or gas but in 2008 electricity has become the dominant energy source in those countries. The share of electricity used in the commercial sector is 53% in USA, 57% in Japan, 46% in Canada, 64% in Korea, 46% in EU in 2008 while it was around 10 to 20% before 1990. In contrast, in 2008 the main type of energy used in the residential sector is gas in those countries.

The driving forces for increased use of commercial electricity are not easy to identify because commercial sector data is not specific and categorization of end-uses is diverse in each country. However lighting, space cooling and ventilation are responsible for a significant portion of commercial electricity consumption in most countries. (Figure 3)

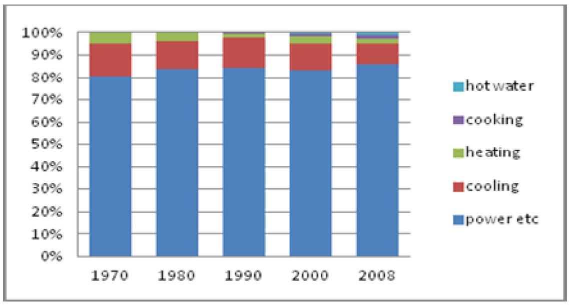
[3] If the European Union is excluded its share would be around 68% of commercial electricity consumption in OECD in 2009.

Figure 3. Trend of commercial electricity consumption share by end-use

< USA >

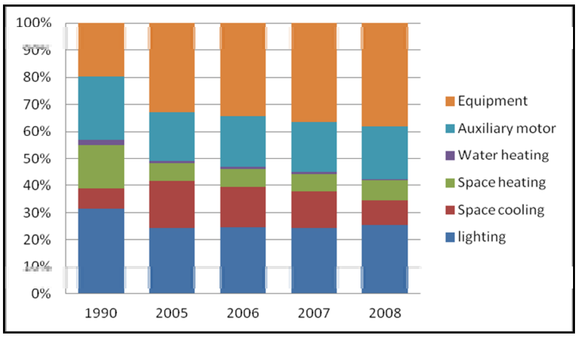


< Japan >

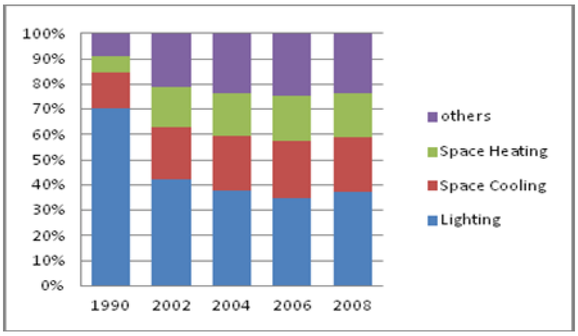


Source: US DOE, 2010. Source: Handbook of Energy & Economic statistics in Japan, 2010.

< Canada >



< Korea >



Source: NRCan, 2009. Source: IEA database.

4. Potential fo electricity savings of commercial equipment by EES&L

The potential of electricity savings of commercial equipment, particularly by EES&L is examined by using the outcomes of existing studies. Unfortunately, only few studies exist that analyzed the electricity efficiency potential of commercial equipment. However, even these studies do not focus on the commercial sector but examine the commercial sector together with the residential sector so as to see the overall potential by energy efficiency polices. Most national or international studies analyzed energy efficiency policies targeting residential appliances.

4.1. World

McNeil et al. (2008) carried out a study of the global potential of EES&L. It is a comprehensive analysis on the energy savings potential of residential appliances and commercial equipment from a global perspective, based on the BUENAS (Bottom-up Energy Analysis System) model[4]. This study covers a broad range of appliances and equipment in commercial and residential sectors. However, analysis of commercial equipment is quite limited due to the lack of detail on commercial equipment type, penetration and use patterns. The study covered the following appliances and equipment ;

- Residential sector: lighting, refrigeration, air conditioning, washing machine, fans, television, standby power, oven, water heating and space heating

[4] It is used to project appliance and building equipment energy use. The BUENAS model forecasts energy consumption of individual equipment categories based on a model using macroeconomic parameters available for a wide range of countries. The BUENAS model was developed at Lawrence Berkeley National Laboratory.

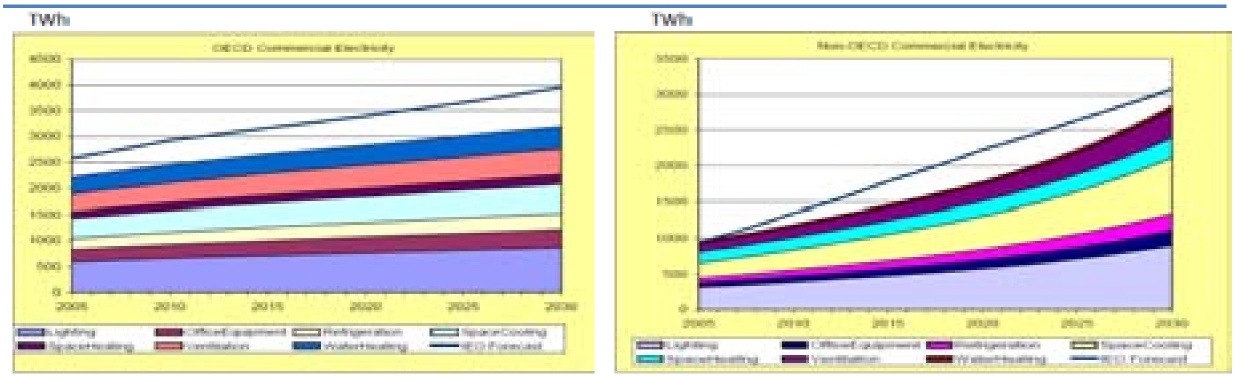
- Commercial sector: lighting, space cooling, ventilation, refrigeration, water heating and space heating

In the case of residential appliances, more detailed analysis was possible from assessing the energy consumption and savings potential at the equipment level. Comprehensive residential data exists since residential end-use is well-characterized and many appliances have already been addressed by various efficiency programs. Furthermore, many countries, including developing countries, conduct surveys of households on ownership and use of major energy-consuming appliances. These surveys assess the living standards of households, but they also obtain data that can be used to forecast ownership of electric appliances in the residential sector.

In this study, the High Efficiency Scenario[5] is based not on technical potential but best current practices of EES&L. This efficiency level is considerably less than the maximum technically achievable level. Cost-effectiveness is also considered implicitly since targets have generally been implemented cost-effectively in some countries already or have been shown to be cost-effective.

Analysis indicates that OECD countries will require most electricity for lighting followed by space cooling, ventilation, water heating and office equipment etc. Non-OECD countries will show a similar trend with increasing share of space cooling but absolute volume for space cooling will be bigger than that of OECD countries in 2030. So most global electricity in the commercial sector will be consumed for lighting and space cooling until 2030 (Figure 4).

Figure 4. Forecast of global electricity demand by commercial equipment



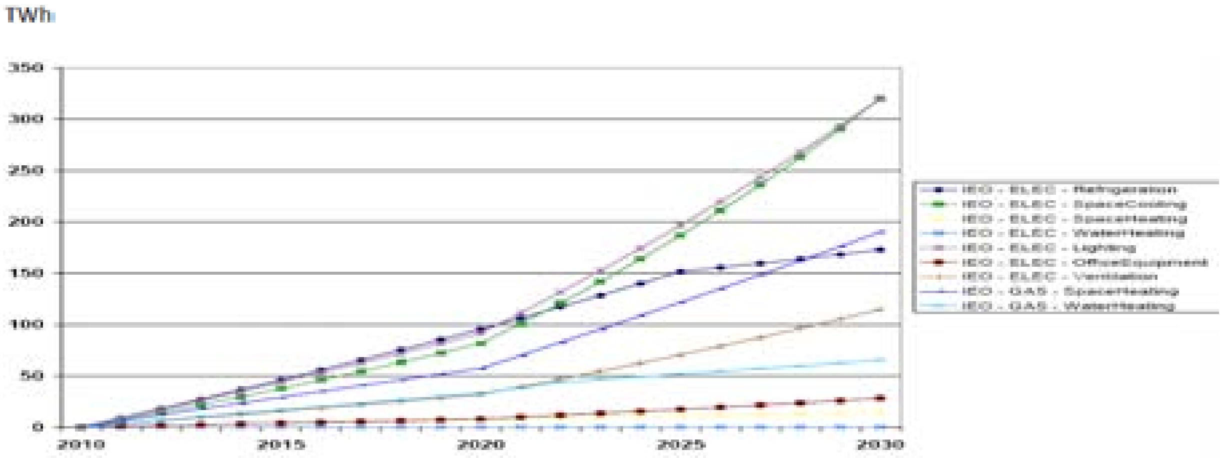
Source: McNeil *et al.,* 2008.

Global potential of electricity savings per year by EES&L is estimated at 1 339 TWh by 2020 and 3 860 TWh by 2030. One quarter of total electricity savings (around 960 TWh by 2030) could be achievable in the commercial sector (Figure 5). In terms of specific end-use, lighting and space cooling have the largest potential (each 320 TWh) followed by refrigeration (170 TWh), ventilation (120 TWh) in the commercial sector by 2030. Up to 2020 the electricity saving potential of refrigeration could be larger than lighting and space cooling but after 2020 the electricity savings potential of lighting, and in particular space cooling, are expected to grow rapidly. For comparison, space heating, refrigeration and television have large electricity savings potential in the residential sector.

This potential savings can be achieved by best current practices. Therefore, the realization of this potential is primarily dependent on political will and administrative capacity.

[5] It is assumed by appliances and equipment, and region considering the programs of EES&L implemented in 2010 and 2020. See p 42-69 of McNeil *et al*., (2008).

Figure 5. Global electricity[6] saving potential of commercial equipment by EES&L



Source: McNeil *et al.,* 2008.

The potential of CO_2 emission reduction by end-use can also be estimated by using electricity generation carbon factors. In the commercial sector the greatest potential for CO_2 emission mitigation was found in space cooling with 214 Mt CO_2 in 2030. Commercial lighting affords the next highest potential in that sector with 203 Mt CO_2. But in residential sector refrigeration could avoid the largest amount of 304 Mt CO_2 in 2030, followed closely by lighting with 292 Mt CO_2.

4.2. United States

Rosenquist *et al*., (2006) analyzed the US national electricity saving potential of MEPS for residential and commercial appliances and equipment. In this study the authors used life cycle cost (LCC)[7] analysis, which includes the initial capital cost and the operating costs over an assumed lifetime with operating costs discounted to a present value.[8] If technologies that are more energy efficient than the baseline technology have a higher LCC than the baseline, those are not included. The Baseline Scenario was the reference energy consumption projection in the Annual Energy Outlook (AEO) of EIA 2004 through 2025, which includes all standards already promulgated by US DOE as of 2004 without standards under consideration. Energy savings potential was estimated over the lifetime of products installed in the 2010-30 period. This study covered the following appliances and equipment ;

- <u>Residential sector</u>: space heating (gas furnace, heat pump); air conditioning (room air conditioner, central air conditioner and heat pump); refrigeration (refrigerator); water heating (electric and gas water heater); clothes washing (clothes washer); lighting (torchière); electric motors (ceiling fan, pool pump, well pump, miscellaneous small motors); and domestic electronics (audio, set-top box, telephony, microwave oven).
- <u>Commercial sector</u> : space heating (gas furnace and boiler); air conditioning (air-source and water-source air conditioner and heat pump); ventilation (air distribution, hot and chilled water circulation cooling water circulation, heat rejection); lighting (fluorescent lamp, High-intensity Discharge - HID - lamp); water heating (gas-fired storage water heater, gas-fired instantaneous water heater); refrigeration (supermarket units, reach-in freezers and refrigerators, refrigerated vending machines, walk-in coolers and freezers); and office equipment (PCs and monitors).

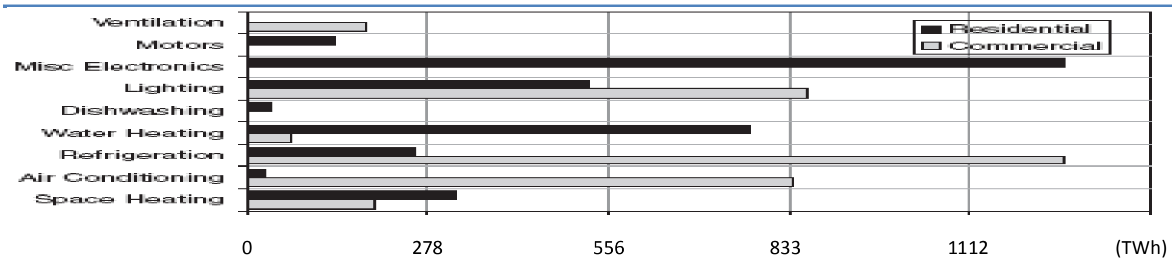
[6] The estimated savings potential of space-heating and water-heating included saving potential by electricity as well as by other energies such as natural gas, liquefied petroleum gas (LPG), oil, district heating etc.

[7] To calculate LCC average electricity prices were used.

[8] Authors used discount rates of 3% and 7% to calculate present value terms in 2004.

During 2010-2030 cumulative potential[9] of electricity savings by appliance and equipment was found to be 7 167 TWh, which is composed of 3 834 TWh by commercial equipment and 3 333 TWh by residential appliances. The largest electricity savings potential by sub end-use was for residential electronic products (1 250 TWh) and commercial refrigeration (1 250 TWh). But the estimate for residential electronic products was considered to have a high degree of uncertainty because various products are included in this group. The next largest savings potential comes from standards for commercial lighting (861 TWh), and commercial air conditioning (833 TWh) (Figure 6). The main conclusion of this study is that commercial equipment has more potential of electricity savings than residential appliances.

Figure 6. Potential of electricity savings by MEPS, United States



Source: Rosenquist *et al*., 2006.

The cumulative present value of energy savings potential by commercial equipment would be USD 58.6 billion at a 3% discount rate and USD 27.2 billion at a 7% discount rate while the present value of savings potential for residential appliances would be USD 45.1 billion at a 3% discount rate and USD 17 billion at a 7% discount rate.

4.3. European Union

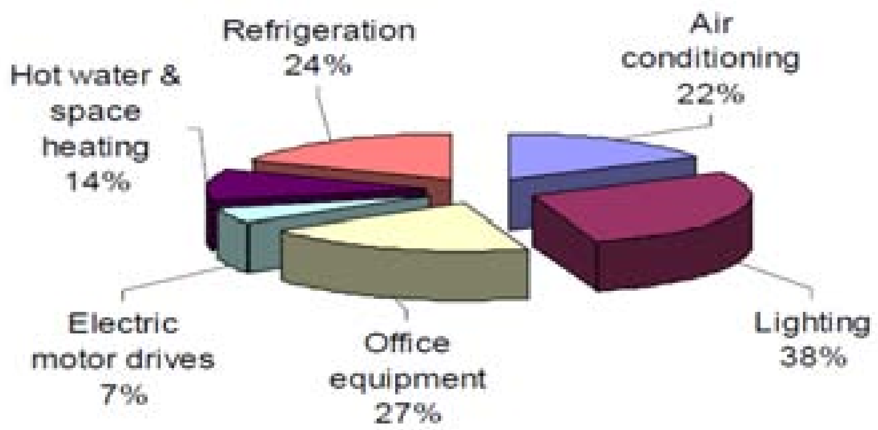
Gruber *et al*., (2008) carried out a comprehensive study to promote electricity savings and a more efficient use of electricity in the commercial sector. Detailed and reliable information on electricity consumption in this sector was deemed necessary for the identification of suitable energy efficiency policies. One of the main aims of this study was to create the technical and methodological foundation for a comprehensive and unified European-wide database.

After analysis of information from existing studies, a methodology was developed for metering and data collection. With this methodology the potential of electricity savings was simulated for a few sample countries for which the metered data are of sufficient quality such as France, Germany, Italy and Netherland. It did not produce concrete outcomes on an EU level like the electricity savings potential of commercial sector in total or by sub end-use. The only percentage of savings potential by sub end-use was estimated with some assumptions[10], which were based on the impact of certain technologies. This is feasible in one or two years without considering deep building refurbishment or restructuring. (Figure 7)

[9] The estimated savings potential of space-heating and water-heating included saving potential by electricity as well as by other energies such as natural gas, liquefied petroleum gas (LPG), oil, district heating etc.

[10] See p 96 of Gruber *et al*., (2008) "Report on the Project Result (Deliverable D26) of Monitoring electricity consumption in the Tertiary sector".

Figure 7. Percentage of potential of electricity savings by sub end-use by EES&L, EU



Source : Gruber *et al*., 2008.

Review of existing studies shows that the global potential of electricity savings by commercial equipment is around one third of that of residential appliances. In the commercial sector, lighting and space cooling have the largest demand and savings potential. In the residential sector, refrigeration and space heating have large saving potential. However, the situation in the United States is a little different. Total electricity savings potential of commercial equipment is bigger than that of residential appliances. The United States has the biggest potential for electricity savings in specific end-use of refrigeration followed by lighting and space cooling in the commercial sector.

4.4. Benchmarking study on commercial air conditioners in Australia

From the review of electricity savings potential by EES&L one of the promising end-uses for electricity savings in the commercial sector was space cooling. Its demand is forecast to rise rapidly and the electricity savings potential is also large. This benchmarking study is made to see electricity savings potential of commercial air conditioners compared with residential air conditioners in Australia which has good MEPS for air conditioners. Commercial lighting has also large demand and potential saving but it has already been covered by energy efficiency policies in many countries and most lighting can be used for residential and commercial uses. So focus is put on space cooling in this study.

In Australia federal and state regulators categorise equipment only by electrical input, and not by the expected end-use, for the purposes of regulation. So there is no legal or official categorisation of commercial air conditioners. However, some equipment is used mostly in the commercial, rather than residential, sector. For the purpose of analysis certain types of air conditioners, which are mainly used in the commercial sector, are considered as commercial air conditioners and these are as follows:

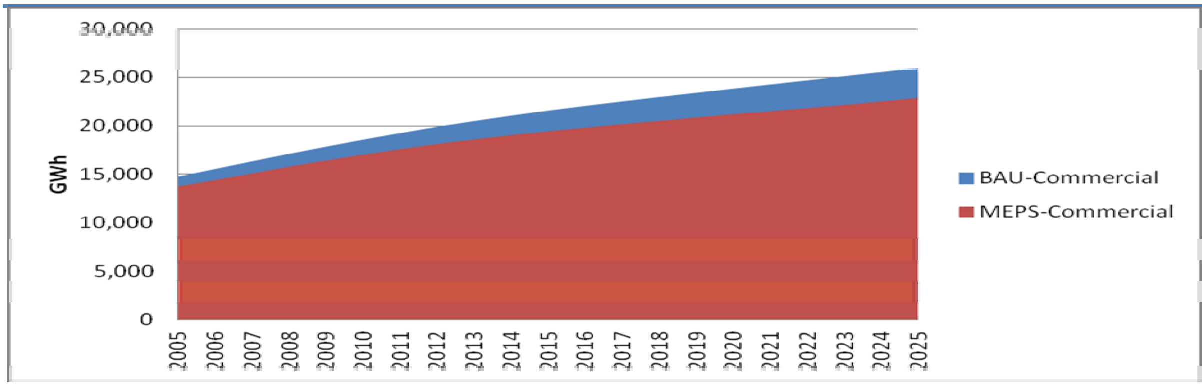
- Three-phase ducted and non-ducted systems;
- All chillers designed for space cooling;
- All close control or precision air conditioning systems

Since 1 October 2001, three-phase air conditioners with a cooling capacity of up to 65 kW manufactured in, or imported into Australia, have been required to comply with MEPS while residential (single-phase) air conditioners have been subject to MEPS since 1 October 2004. MEPS for chillers with a cooling capacity of greater than 350 kW and Close control air conditioners (CCAC) was introduced in Australia in 2009.

To estimate potential of electricity savings by commercial air conditioners, a bottom-up analysis is used by totalling electricity consumption generated in a detailed model of the stock of commercial AC. The stock model estimate the number of operating units in a particular year based on a function of existing stock, replacements and new sales. Unit energy consumption is calculated for each equipment category based on estimates for average efficiency, average capacity and typical operating hours[11]. The combination of the unit energy consumption and stock model provided total energy consumption estimates from 2005 to 2025 for BAU and MEPS scenarios.

Electricity savings potential of commercial air conditioners by MEPS across the 20 years is estimated at 44 TWh. Annual savings will be 1 670 GWh in 2011 which is approximately 9% against BAU electricity consumption of 19 252 GWh. It will exceed 2 654 GWh by 2020 and more than 3 065 GWh by 2025. (Figure 8)

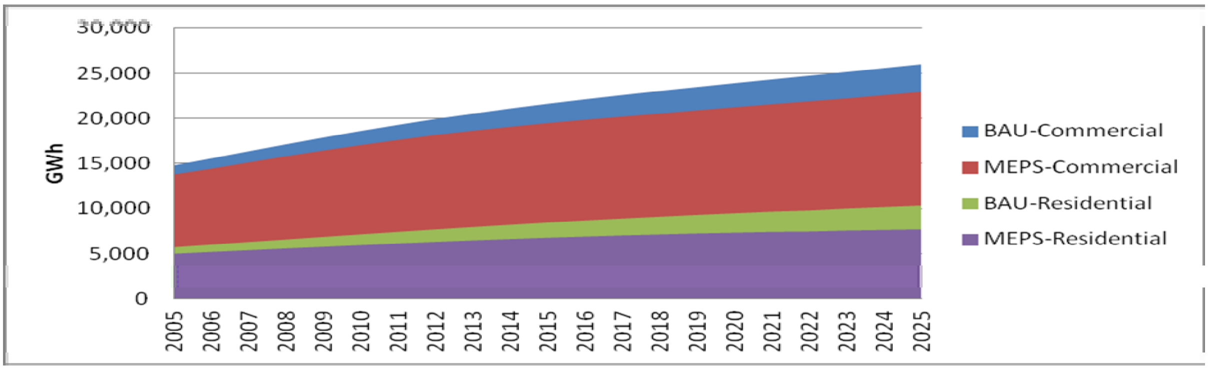
Figure 8. Potential of electricity savings by MEPS on commercial AC in Australia



Source: Michael McCann , 2011

For comparison electricity savings potential by residential AC is 2 162 GWh in 2020 and 2 653 GWh in 2025, which are approximately 85% of commercial AC. The number of residential AC installed would be around 11.7 million – about 10 times of commercial AC of 1.27 million in 2025. However, commercial AC is forecast to consume electricity equivalent to around 26 000 GWh in 2025, which is more than double that consumed by residential AC. (Figure 9)

Figure 9. Electricity saving potential by MEPS on residential and commercial AC in Australia



Source: Michael McCann , 2011

[11] Data sources reviewed included ABARES data from the Australian Fuel and Electricity Survey, Refrigerant gas pre-charged equipment import data for stationary AC including categories for chillers, packaged air/water cooled, window, portable, multi-split/VRV, single-split and other ACs, Sales and existing stock information from recent Regulatory Impact Statements prepared for the Australian Federal Government, Industry statistics and interviews with importers and local manufacturers, and Australian Bureau of Statistics import data prior to 2005.

In this benchmarking analysis it is also found that electricity savings potential by commercial AC in Australia is significant and even bigger than residential one like in USA.

5. Barriers to energy efficiency (policies) for commercial equipment

To develop effective energy efficiency policies it is crucial to understand barriers to energy efficiency. Most barriers to energy efficiency are also applied to commercial equipment. However, certain barriers can be more influential on commercial equipment than residential appliances. Due to size and characteristics of commercial equipment externalities, imperfect competition, liquidity constraints can more hinder uptake of efficient commercial equipment.

- Commercial equipment is bigger and uses more electricity than residential appliances so inefficient but cheap one can be more attractive in commercial sector if energy price is lower than socially optimal level due to externalities.
- Commercial equipment is more diverse in model and size that fewer producers and less competition can not have sufficient market force of leading to producing efficient products.
- Commercial equipment requires more up-front investment that liquidity constraint like lack of access to credit can make consumer easily choose cheap but inefficient one.

In regard to the asymmetric information problem, the commercial consumers have more resources to get information than residential consumers. This means that information gap between consumers and producers may be smaller. However, it is not clear whether commercial or residential consumers are more influenced by the principal-agent problem or bounded rationality.

In addition to these barriers to energy efficiency, something else should be noted. In examining energy efficiency policies for commercial equipment it is found that additional barriers exist for energy efficiency policies.

The first one is heterogeneity of product and sub-sector. Commercial equipment varies in size and specification with a relatively limited production of each product. They range in a wide spectrum from something similar to small residential to large industrial appliances. Sub-sectors in the commercial area are quite diverse including office buildings, hospitals, super-markets, hotels, schools, universities etc. They have quite heterogeneous economic and energy-related characteristics while the residential sector has homogeneous characteristics. This makes it difficult to develop measures for them all.

The second one is the scarcity of available information on the commercial equipment. This is perhaps quite closely related to the first aspect as it is expensive to obtain information due to the variety of products and the lacking interest in this area. Energy efficiency-related information, even general data or information on market trends of products, is very limited. A small number of countries enjoy sound data. Due to the lack of consistency in each country's information, it is also difficult to take an overview of commercial equipment regionally or globally.

The third one is lack of established objective and quantitative methods to measure the energy efficiency of commercial equipment. Even if there is sufficient and relevant information, credible methodologies are required to test the efficiency level of equipment for policy development. It may not be a matter of developing new technologies but rather investigating how to apply existing technologies to commercial equipment.

Table 1 provides a summary of potential market and behavioural failures including "barriers to energy efficiency policies" relating to appliances and equipment along with policy responses that could be implemented to address these problems. The influence of the barriers on commercial equipment and residential appliances is indicated with H (high impact), L (low impact). In most cases EES&L are effective directly or indirectly. MEPS is regarded as the most effective measure to address barriers such as principal agent problem, information failures and behavioural failures by eliminating the worst performing products in the market[12]. Labelling is primarily aimed at providing information on the energy performance of appliances and equipment in order to overcome the barrier of imperfect information. But it also contributes much to overcome the other barriers by facilitating energy efficiency policies since information of energy performance by labelling is used to identify the efficient products, which are the targets of tax credits, grants, low interest loans, procurement policies, utility obligations etc. It is quite desirable to implement both MEPS and labelling which are complementary each other. The role of MEPS is quite critical when there is no labelling program on prodcuts. Therefore, EES&L is considered key policies for appliances and equipment.

Table 1. Comparison of influence of barriers to energy efficiency on commercial equipment

Barriers to Energy Efficiency	Commercial equipment	Residential appliances	Policy options
Potential market failures			
a. Externalities	H	L	Energy or Carbon pricing
b. Imperfect competition	H	L	Competition policy (EES&L)
c. Asymmetric information	L	H	EES&L
d. Principal-agent problems	H	H	EES&L
d. Limited access to capital	H	L	Financing / loan program (EES&L)
Potential behavioral failures			
Bounded rationality	H	H	EES&L
Additional barriers to energy efficiency policies	H	L	Poractive and strategic EE policies

6. Energy efficiency policies (EES&L) for commercial equipment

MEPS is the most favoured energy efficiency measure for the commercial equipment in most countries, which have typically been introduced later than for residential appliances. The United States has a separate category of MEPS for commercial equipment and is the first country to introduce the MEPS for commercial equipment like commercial lighting, commercial air conditioners, commercial boilers, and commercial water heater in 1992 followed by Canada, Japan etc. USA has the broadest coverage of MEPS for commercial equipment. Coverage of MEPS for major commercial equipment by the various countries is as follows ;

Table 2 Coverage of commercial equipment by MEPS in OECD countries

	Australia	Canada	Japan	Korea	New Zealand	USA	EU
Commercial lighting	•	•	•	•	•	•	•
Commercial refrigerator or freezer	•	•	•	•	•	•	

[12]See p 23 of IEA (2011), "Energy Efficiency Policy and Carbon Pricing"

Commercial air conditioners	•	•	•	•	•	•	
Vending machine		•	•			•	
Commercial ice maker		•				•	
Distribution transformer	•	•			•	•	
Commercial motor	•	•		•	•	•	
Commercial boiler						•	
Commercial water heater						•	
Commercial clothes washers						•	

The range of individual commercial equipment covered by MEPS varies from country to country. For example, the range of commercial air conditioners and heat pumps covered by MEPS is different depending on countries. (Table 3)

Table 3 Range of commercial AC and HP by MEPS in OECD countries

Country	Capacity	
USA	< 220 Kw	including PTAC, small and large Packaged or Split AC
Japan	< 50.4 Kw	by Top runner program (except for water cooling type, separate type to connect more than two indoor units to one outdoor unit etc)
Canada	< 70 Kw	including Chillers
Australia	< 65 Kw	including Chillers, Close control AC
New Zealand	< 65 Kw	including Chillers, Computer room AC
Korea	•20kW - <70 Kw	Variable refrigerant flow multi-split heat pumps

Endorsement labels like ENERGY STAR is the next favoured measure for commercial equipment. The common target of ENERGY STAR, which is introduced in many countries of Japan, Canada, EU, Australia and New Zealand etc, is office equipment. But the United States and Canada have broader coverage ; USA has a similar coverage of ENERGY STAR to MEPS while Canada has more commercial equipment subject to ENERGY STAR than MEPS. Japan, Australia and New Zealand apply ENERGY STAR only to office equipment. In Korea “high efficiency appliances certification programme” as an endorsement label is used mainly for commercial equipment.

The comparative label is used as a voluntary measure for some commercial equipment such as commercial AC in Canada and Australia while it is usually a mandatory scheme for residential appliances.

At the EU level, “Ecodesign” and “European Eco-label” are implemented, which are equivalent to MEPS and the comparative label, but so far only few commercial equipment like lighting, electric motors, circulator, fans are covered by Ecodesign. Residential appliances and office equipment are subject to ENERGY STAR.

To sum up, coverage of commercial equipment by EES&L is not as wide as for residential ones even in USA where MEPS is most widely implemented. In USA the products covered by MEPS are responsible for 67% commercial energy consumption while they are responsible for 82% of residential energy consumption[13]. In Japan only 20% of commercial equipment is covered by Top runner program[14]. Significant room is still available for further energy efficiency policies for commercial equipment.

7. Conclusion

Electricity consumption in the commercial sector has been growing rapidly and is expected to maintain its status as a major energy source in the commercial sector. Particularly the share of commercial electricity use in total electricity consumption is largest in developed countries. Considering most electricity is used by commercial equipment the potential of electricity savings by commercial equipment is relatively large. More effort is therefore needed to develop appropriate energy efficiency policies for commercial equipment since it is found that energy efficiency policies for commercial equipment has not been sufficiently developed yet. And there are many barriers to overcome in the commercial sector. The traditional barriers to energy efficiency for commercial equipment are not smaller than those for residential appliances and additional barriers also hinder the development of energy efficiency policy for commercial equipment due to heterogeneous economic and energy-related characteristics. This analysis suggests that the challenges for realising the untapped electricity savings potential of commercial equipment should be immediately addressed for both developed countries as well as developing countries[15] and recommends that policymakers take the following actions:

Firstly, **establish or improve systems as soon as possible to collect information on commercial equipment**. Currently, even basic information is unavailable. It may be harder to collect than is the case in the residential sector as the wide-ranging products and sub-sectors have heterogeneous economic and energy-related characteristics. But relevant data on commercial equipment is necessary for the development of energy efficiency policies and this becomes easier to maintain once systems have been established. We cannot defer any longer.

Secondly, embrace **a more proactive approach on energy efficiency policies for commercial equipment**. Information is necessary for development of energy efficiency polices. However without policies it is getting difficult to get information. Relating to first point it may be regarded as the question “which came first, the **chicken** or the **egg**?” Currently there is vicious cycle of insufficient information • less attention • few policies • to lose opportunity of energy saving • information is still insufficient. However, a more proactive approach to energy efficiency policies would create the virtuous cycle of policy measures • creating more information by monitoring and evaluating the measures • more attention • better policies. Strategic targets would be commercial lighting, commercial air conditioners and commercial refrigerator which have large savings potential. In particular commercial air conditioners are getting important since temperatures will increase due to climate change as well as improved insulation and increased use of ICT products will cause more cooling load inside the building.

Thirdly, **increase international co-operation in sharing the experiences and knowledge on measuring the energy efficiency of commercial equipment**. Technical knowledge of energy efficiency measurements on commercial equipment is an essential component of policy development but this can differ from that for residential appliances. Some countries have already developed measurements for energy efficiency policies and it is recommendable, and beneficial, that they share these with countries that are still in the process of introducing such policies.

Fourthly, it is **recommendable to start with MEPS or endorsement labels for commercial equipment and regularly update its stringency.** When introducing energy efficiency measures for commercial equipment, the most appropriate polices or measures should cater for the characteristics of commercial equipment. In the case of residential appliances, MEPS and comparison labels are quite common in most countries, but for commercial equipment the comparison label is not suitable and MEPS or the endorsement label is preferred. Commercial equipment differs from residential appliances in that it is usually neither mass-produced nor displayed in a shop window. While little benefit is expected from the

---

[13] See page 7 of “Multi-Year Program Plan: Building Regulartory Programs” by DOE (2010)

[14] See page 9 of “Top Runner Program” revised edition by METI (2010)

[15] Otherwise developing countries will get the products that can no longer be sold in developed countries that have MEPS.

cost of comparison labels, MEPS helps to eliminate low-efficiency products with very low per unit transaction costs and also make it relatively easy to ratchet levels periodically. But MEPS is usually a mandatory programme so it requires consensus among multiple stakeholders and sufficient data. For its successful implementation, a sound enforcement policy is required. If the conditions for MEPS are not satisfied then an endorsement label is a sound alternative. It is usually a voluntary measure, which allows manufacturers to opt in or not and ensures efficiency and quality and can have a large impact if the endorsement level becomes a de facto standard. Compared to MEPS, endorsement labels could be a good way to promote awareness of efficient products with fewer burdens on producers and provide opportunities for policymakers to collect relevant information on equipment.

Finally, the authors would like to emphasise few points. Appliances and equipment are very important by themselves and the energy efficiency of individual appliances and equipment is critical part of the whole energy system. Greater efficiency in equipment is beneficial where all the other conditions are the same. However, considering energy efficiency of system (e.g. Data Centre[16]) or buildings where commercial equipment is used other factors such as selection of proper dimension of equipment, the design of building envelope including windows, and management system of internal cooling load created by people and other equipment like lighting, information and communication technology (ICT) appliances etc., can also substantially improve energy efficiency. More efforts should be made to improve energy efficiency from both holistic and systematic viewpoints in the future.

References

[1] Building Energy Databook 2010, US DOE.

[2] Branz Ltd (2007), "An Assessment of the Need to Adapt Buildings for the Unavoidable Consequences of Climate Change", Report No EC0893 for the Australian Greenhouse Office.

[3] Blumstein, C., Kreig, B., Schipper, L. and York, C., 1980, "Overcoming Social and Institutional Barriers to Energy Efficiency", Energy 5(4): 355-72.

[4] Berry, L., 1984, "The Role of Financial Incentives in Utility-Sponsored Residential Conservation Programs", A Review of Customer Surveys. Evaluation and Program Planning 7: 131–41.

[5] Department of Energy (2010) Multi-Year Program Plan: Building Regulartory Programs

[6] Department of Resources Energy and Tourism, (2010) 'Energy in Australia 2010'.

[7] Department of Resources Energy and Tourism, (2010) 'Energy in Australia 2011'.

[8] EnergyConsult Pty Ltd, (2008) "Decision Regulatory Impact Statement: Minimum Energy Performance Standards and Alternative Strategies for Close Control Air Conditioners", for the Equipment Energy Efficiency Committee.

[9] Energy Consult Pty Ltd, (2008) "Decision Regulatory Impact Statement: Minimum Energy Performance Standards and Alternative Strategies for Chillers", for the Equipment Energy Efficiency Committee.

[10] EnergyConsult Pty Ltd, (2010) "Consultation Regulatory Impact Statement: Minimum Energy Performance Standards for Air Conditioners 2011", for the Equipment Energy Efficiency Committee.

[11] EnergyConsult Pty Ltd, (2010) "Evaluation of Policy Measures for Household Air Conditioners in Australia", for the Equipment Energy Efficiency Committee

[16] Electricity consumption by Data Centre is increasing and US ENERGY STAR is applied to Data Centre and EU developed Code of Conduct for Data Centres.

[12] Energy Strategies Pty Ltd (2007), "Cold Hard Facts: The Refrigeration and Air Conditioning Industry in Australia", for the Australian Department of Environment and Water Resources.

[13] George Wilkenfeld and Associates, (2009) "Prevention is Cheaper than Cure – Avoiding Carbon Emissions Through Energy Efficiency; Projected Impacts of the Equipment Energy Efficiency Program through to 2020", for the Equipment Energy Efficiency Committee.

[14] Gruber, E. et al, (2008), "Report on the Project Result (Deliverable D26) of Monitoring electricity consumption in the Tertiary sector", Intelligent Energy Europe.

[15] Handbook of Energy & Economic statistics in Japan (2010).

[16] Hirst, E. and Brown, M., (1990), "closing the efficiency gap: barriers to the efficient use of energy", Resources, Conservation and Recycling. 3 : 267- 281.

[17] IEA (2007) "Mind the gap", IEA/OECD Paris.

[18] IEA (2009) "Gadgets and Gigawatts", IEA/OECD, Paris.

[19] IEA (2011) "World Energy Outlook 2011", OECD/IEA, Paris.

[20] IEA (2011), "Energy Efficiency Policy and Carbon Pricing", OECD/IEA, Paris

[21] Jaffe, A. and Stavins, R. (1994), "The Energy Paradox and the Diffusion of Conservation Technology", Resource and Energy Economics. 16 (2): 91-122.

[22] McMahon, J.E., (2011), Presentation of "Energy Efficiency Policies for Appliances" at IEA Energy Training and Capacity Building Week at Paris, April 2011, Lawrence Berkeley National Laboratory.

[23] Gilligham, K. et al (2009), "Energy Efficiency Economics and Policy", Resources for the Future.

[24] Golove, W.H. and Eto, J.H. (1996), "Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency", Lawrence Berkeley National Laboratory, University of California Berkeley, California.

[25] McNeil, M.A. et al (2008), "Global Potential of Energy Efficiency Standards and Labeling Programs", Lawrence Berkeley National Laboratory.

[26] METI (Ministry of Economy, Trade and Industry) Agency for National Resources and Energy (2010), "Top Runner Program" revised edition.

[27] Michael McCann, Thinkwell Australia Pty Ltd, "The Efficiency Opportunity in Air Conditioning, An Australian Case Study" 2011 , internal report presented for this work as co-authors

[28] O'Malley, E., Scott, S. and Sorrell, S., (2003), "Barriers to Energy Efficiency: Evidence from Selected Sectors", The Economic and Social Research Institute, Dublin.

[29] Rosenquist, G., (2006), "Energy efficiency standards for equipment: Additional opportunities in the residential and commercial sectors", Energy Policy, Elsevier, Vol 34, pp 3257-3267.

[30] Sanstad, A.H. and Howarth, R.B. 1994. "Consumer Rationality and Energy Efficiency", presented at proceedings of the 1994 Summer Study on Energy Efficiency in Buildings, Berkeley, CA.

[31] Tversky A., 1972. "Elimination by Aspects: A Theory of Choice", Psychological Review 79: 281–99.

[32] Appliance Standards Awareness Project website (www.standardsasap.org/federal.htm).

[33] Energystar website (www.energystar.gov/index.cfm?c=about.ab milestones).

[34] NRCan website (http://oee.nrcan.gc.ca/regulations/guide.cfm?attr=0).

[35] NRCan website (http://oee.nrcan.gc.ca/residential/business/manufacturers/qualified-products.cfm?attr=4).

[36] EU Ecodesign website (http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/index_en.htm).

[37] EU Ecolabel website (http://ec.europa.eu/environment/ecolabel/ecolabelled_products/product_categories_en.htm).

[38] EU Energystar website (www.eu-energystar.org/en/database).

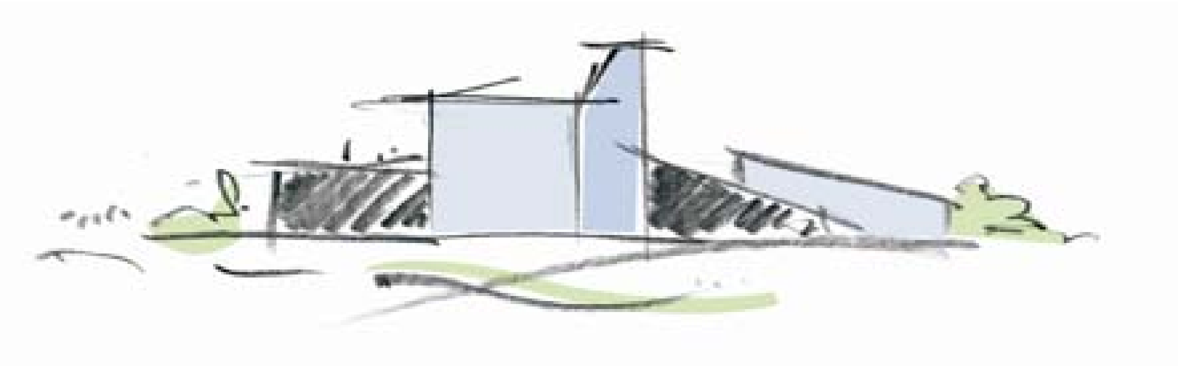
[39] Australia Energyrating website (www.energyrating.gov.au/meps1.html).

[40] Australian website (www.energystar.gov.au/products/index.html),

[41] New Zealand websites (www.eeca.govt.nz/products), (www.eeca.govt.nz/standards-and-ratings/minimum-energy-performance-standards-and-labelling/current-product-standards).

How to Achieve Low-energy Building Design

Thomas Drivsholm and Dorthe Bechmann



Abstract

Many construction clients want to build energy efficiently, but in real life they encounter numerous barriers that prevent their ambitious energy saving targets from being fulfilled at project end. The challenge is to ensure that the focus on energy efficiency is maintained throughout the construction process.

Construction clients have the most direct interest in the future energy consumption and energy bills over the lifetime of their use of a building. Consequently, they also have the most incentive to take responsibility for the process, thereby ensuring the necessary focus on energy efficiency throughout the design and construction phases of the project. It is only on this basis that the building will meet requirements that exceed the minimum standards set by national building regulations. However, since clients do not usually have the necessary expertise and knowledge they need help throughout the process and all the phases. The project described in this paper introduces the concept of using an energy evaluator with in-depth knowledge about all aspects of the process. The Danish Energy Saving Trust has developed guidelines for construction clients to help them create a construction process that meets their energy saving targets [1].

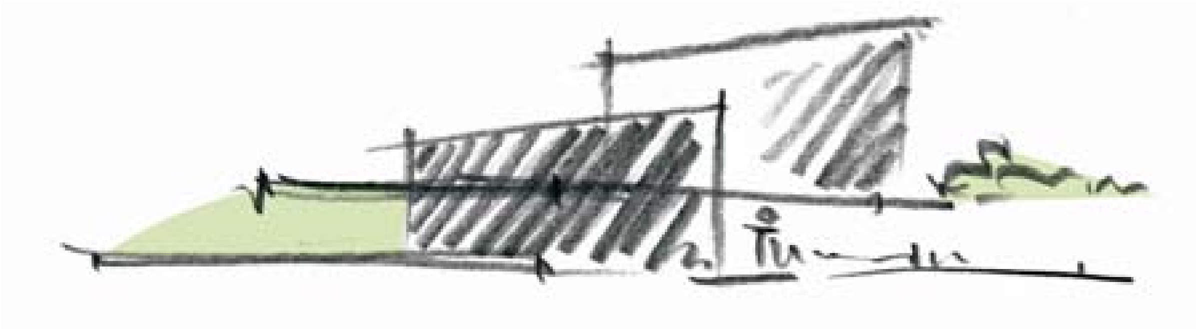
When it comes to large buildings the challenge is to be able to foresee the consequences of each of the decisions taken during the process. To help construction clients in this situation, the guidelines focus on how the clients can organise the process, thereby ensuring that targets based on the energy saving ambitions identified are met from project start.

The guidelines will help construction clients to understand that they play a key role, and that they are ultimately responsible for the overall energy efficiency of the completed building.

Introduction

The energy characteristics of a building are more or less established when the first drawings leave the architect's desk, but the characteristics are also influenced by decisions taken during the construction process. The parties involved in the construction will normally only plan and construct a building so that it exactly fulfils the energy requirements in the building regulations. However, with early stage input, the right choice of components, effective follow-up and target management, construction clients can have a much more energy efficient building than they would otherwise have achieved by simply conforming to the minimum standards in the building regulations.

A number of barriers and incentives have been identified. A study carried out by the Danish Knowledge Centre for Energy Efficient Buildings [2] concluded that professionals, construction clients and the construction process are confronted with many and different barriers. Furthermore, although there are a variety of possible ways of reducing consumption, many parts of the value chain (architects, engineers, manufacturers, craftsmen, financing institutions, etc.) need to be motivated to implement savings successfully.



Construction Process Guidelines 2011

The guidelines provide construction clients with a strategy, advice and tools to create a process whereby all parts of the construction value chain are motivated to make an extra effort to optimise and implement energy efficiency throughout the construction process. In order to achieve this, it is important to look at ways of incentivising the different partners in the value chain.

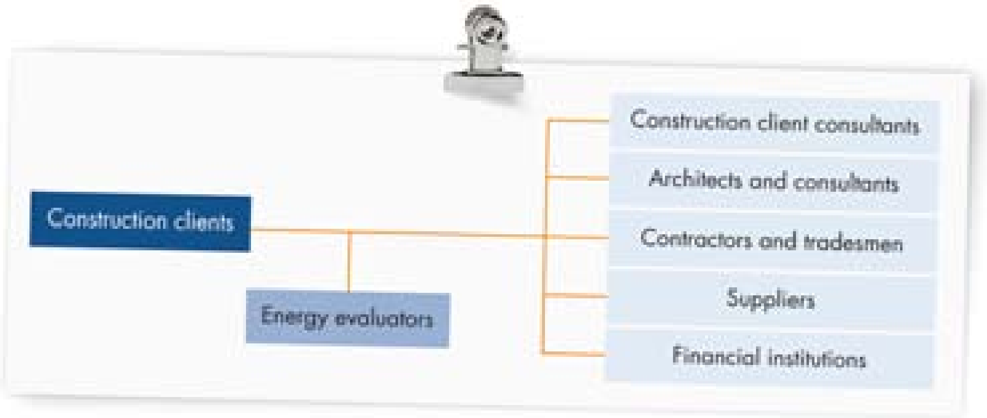
The guidelines are primarily aimed at construction clients, but the target group also includes architects and engineers who want to build energy efficiently.

The tools and expertise necessary for clients who want to achieve greater energy efficiency include:

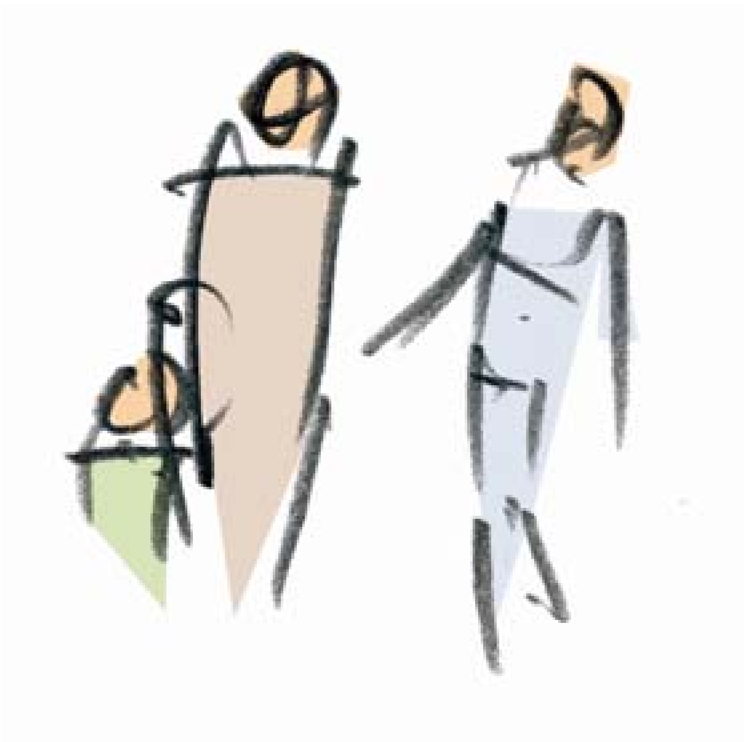
- The inclusion of an independent energy evaluator in the process. The role of the evaluator is to keep energy efficiency on the agenda throughout the construction process, from the beginning of the design phase and until the building is finalised. The evaluator should be a suitably qualified professional engineer or architect with broad experience in energy evaluation.
- An overview of what the challenges in the process are, and how to deal with them. The guidelines suggest a number of discussions and questions for construction clients. In particular these focus on the role of the client at the beginning of the project, and how the client can prepare for the challenges encountered during the process.
- Tools for evaluating the financial aspects, and how to set realistic targets. The guidelines describe different ways to evaluate the finances of a project, for example, focussing on the finances over the lifetime of the project as an alternative to a simple comparison of investment costs.
- Efficient ways of organising the construction process, and how best to allocate responsibility for the energy efficiency of the completed building. The guidelines show the need for a well-defined energy evaluation strategy; the need to allocate resources for energy evaluation during both the design phase and the construction process; and the need to provide and communicate information about the energy requirements and targets. The guidelines discuss how this can be done by focussing on the organisation of the process.
- Providing guidance on how to set realistic targets for the energy efficiency of the completed building; how to ensure that the targets are incorporated in the design phase, and how to monitor the final building in order to prove the calculations. The guidelines illustrate and discuss how different targets influence the final result and the final energy consumption.

- An overview of important areas on which to focus with regard to energy efficiency. The guidelines go through all the phases in the building process and highlight the most important areas.
- Information about problems faced by "frontrunners" and an overview of the main challenges when trying out new solutions. The guidelines discuss the pros and cons of participating in research and demonstration projects.

One of the main themes is to make construction clients aware that energy efficiency requirements must be specified at the very early stages of the construction process, and well before the design of the building is finalised. Achieving this presents major challenges, so it is often a good idea to get an energy evaluator involved at the planning stage to help organise the pre-tender specifications, and to discuss and evaluate the energy efficiency of the whole project from start to finish.



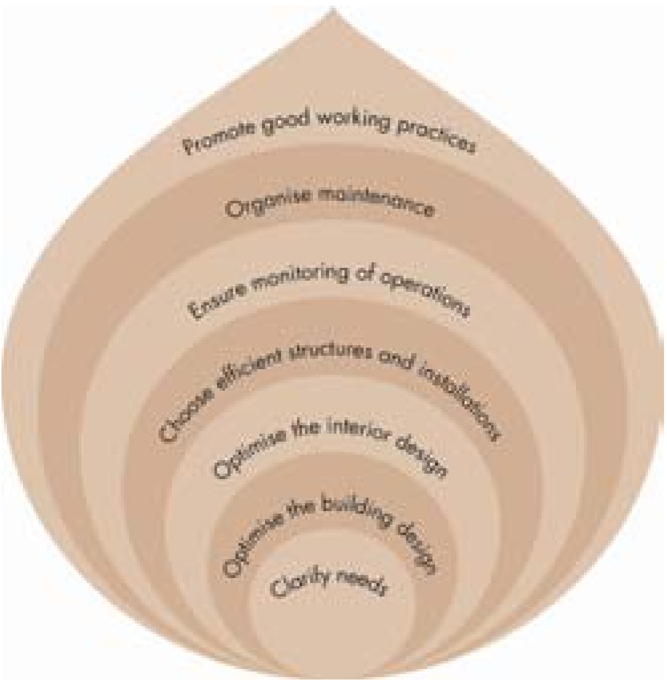
Energy evaluators should be at the heart of the organisation. The project will benefit from the inclusion of an independent evaluator who can focus on the overall energy efficiency and question the design and planning of the building.



The “Onion” diagram

The “Onion” diagram is one method for illustrating the process of achieving low energy consumption in the completed building.

- Start by identifying your needs and requirements. Remember to question what your needs actually are. Some of your needs may turn out to be less important than you first thought
- Optimise the design of the building – and communicate what you decide. Make sure that everyone knows what the goals are. If you want the operating cost to be included make sure that these are clearly stated. Ask for documentation of the calculations
- Optimise the interior design – make sure that the design is compatible with the use of energy efficient lighting and ventilation which avoids the need for active cooling whenever possible
- Optimise the building envelope and the installations
- Make sure that you can monitor and operate the building and manage the energy consumption, preferably by installing a Building Management System (BMS) or a Building Energy Management System (BMES)
- Organise maintenance efficiently and make sure that someone is responsible for monitoring energy consumption and any follow-up
- Promote good working practices. These can include detailed user instructions on the energy efficient operation of the building. Encourage staff to be energy efficient



8 steps to an energy efficient building

The huge number of decisions taken during the building construction process can be overwhelming for construction clients. However, clients are more likely to achieve a successful result by following the 8 simple steps below.

8 steps to an energy efficient building:

1. Take responsibility – it is in your interests
2. Use an energy evaluator
3. Define your needs
4. Focus on what is most important for the energy consumption in the building during the operational phase
5. Factor in energy efficiency from the start, and when switching to the next phase in the process
6. Define goals clearly
7. Try new solutions – maybe/maybe not?
8. Communicate your needs and requirements clearly, and make them specific and binding

The guidelines introduce the concept of using an energy evaluator – an independent specialist with in-depth knowledge of energy efficient buildings. It will often be useful to include the energy evaluator from project start, at the pre-tendering stage for example, to ensure that the tender includes sufficient information about the requirements for use by the project partners. It is important that the construction client is aware of, and understands the significant opportunities that exist for establishing the requirements in the pre-tendering phase. The opportunities for including energy efficiency requirements are much reduced at later stages of the project.

The guidelines include different tools to describe the overall finances of the project. It is essential to include both construction costs and the final operating costs in the evaluation. It is also essential to agree, describe, and communicate clearly how the building should be optimised so everyone in the project team uses the same method. For example, when comparing alternative solutions, base your calculations on the total investment cost plus 10 years of operating costs. An energy efficient ventilator for a ventilation system may cost more initially, but when the energy consumption in the operation phase is included over the lifetime of the device, the more expensive purchase may turn out to be cheapest solution in the long run. It appears that when construction clients request energy efficient solutions some engineers and architects have the impression that clients require expensive "futuristic" solutions and that they are not interested in how much these cost. However, by taking the operating costs into account clients can choose the most financially viable solutions over the long term.

Energy efficient buildings do not need to be circular shaped, have green roofs and spectacular ventilations or cooling systems, or have expensive glass facades. By taking the total operating costs into account early in the design phase, construction clients will often arrive at much cheaper and more efficient solutions with lower maintenance costs over the long term.

The guidelines highlight the opportunities and problems associated with being a "frontrunner". Many construction clients start by being very ambitious, but have insufficient knowledge and information about buildings, costs etc. Construction clients should be aware that it is important to factor energy efficiency into the design of the building from project start.

Last but not least, the guidelines include checklists for use by construction clients (see next page).

At the ideas stage and during the building program phases, focus on:

- ☐ Making sure you have reliable data on future energy needs.
- ☐ Allocating responsibility for energy consumption.
- ☐ Identifying the most important design parameters.
- ☐ Minimising energy needs during the operational phase.
- ☐ Identifying the best technology.
- ☐ Proposing alternative energy efficient solutions and evaluating the overall finances of these.

At the design stage, focus on:

- ☐ Designing energy efficient building envelopes and installations.
- ☐ Integrating energy efficiency into solutions across all areas of the project.
- ☐ Evaluating the requirement to measure, control and regulate.
- ☐ Choosing energy efficient components.
- ☐ Ensuring that there is sufficient space for insulation of the technical installations.

During the tender and bid process, focus on:

- ☐ Setting requirements for energy efficient solutions in the tender documents.
- ☐ Setting requirements for quality control and follow-up on the construction site in the tender documents.
- ☐ Setting requirements for the expertise of the tenderer and their quality control systems.
- ☐ Setting requirements for the guarantee of operational efficiency in the completed building.
- ☐ Ensuring that the energy requirements are legally binding when signing the contract.
- ☐ Ensuring that it is possible to carry out impartial monitoring during the construction phase.
- ☐ Involving yourself in establishing the basis for evaluating alternative solutions for both energy and the indoor climate. Insist on user guidelines, and if necessary courses on the energy optimal operation of buildings.
- ☐ Ensuring that it is possible to carry out sensible energy management of the completed system, including that the system is built in a way that allows for the measurement of relevant part consumption.
- ☐ Ensuring where possible that installations are demand-controlled, and that you consider the most energy efficient method when reducing output.
- ☐ Ensuring, in particular, that installations are operated efficiently during normal output, especially if peak loads only occur for short periods of time. A system running at half power does not necessarily consume half as much energy.
- ☐ Receiving the buildings and the installations in accordance with the written specifications.
- ☐ Ensuring that operating manuals and instructions are properly presented, and that energy efficient operation is described.
- ☐ Ensuring that you are ready to implement energy control of the installations.

Realistic goals are achievable

The guidelines emphasise the importance of setting realistic goals based on the requirements. These can only be defined on the basis of knowledge and understanding of the overall operating conditions, and not just the standard operating conditions. The guidelines also discuss the importance of establishing a goal-setting framework. Consumption per square meter is one of several possible scenarios, but goals can also be set on the basis of CO_2 emissions, lowest energy costs, energy consumption per member of staff, etc. Whatever the method used, it is important to compare alternative solutions on a total cost basis, i.e. that the evaluation should also take the operating costs and maintenance overheads into account.

In other words, the guideline encourage construction clients to ask detailed questions, thereby ensuring that they include specific, measurable, achievable, time delimited and realistic energy efficiency goals as the basis for any good project.

Where are the problems?

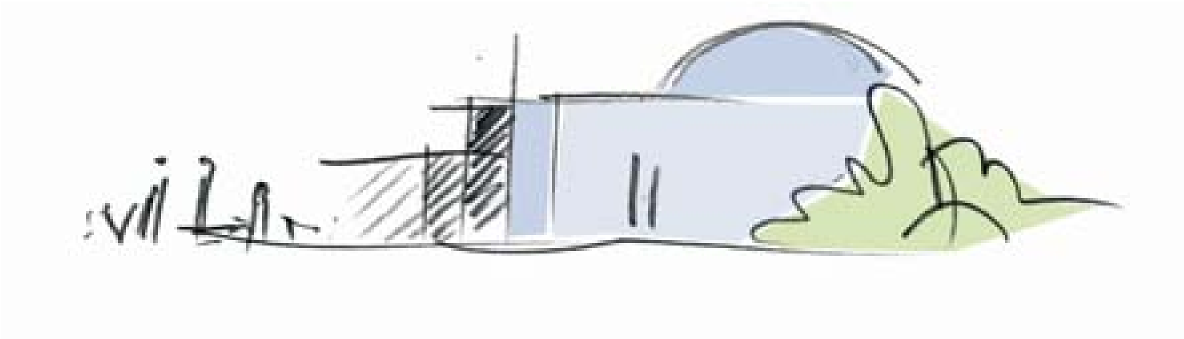
Lack of expertise and knowledge of the construction process is a major issue for unprofessional construction clients, but even very professional clients face problems in their attempts to put energy efficiency on the agenda and maintain their ambitious targets throughout the construction process. Construction clients are not simply purchasing a product. Because the construction process includes decisions taken over a long timeframe, clients often lack the expertise to work out the consequences of decisions taken. Also, during the design process they do not, or forget to, focus on energy efficiency. At the same time clients may not be qualified to know how the building could be optimised, or are unable to evaluate how design changes can improve the cost effectiveness of the building over the long term. Another important issue is that the energy consumption is influenced by the way the building is used. Many buildings are designed to fulfil requirements that bear little relationship to the way the building is ultimately used in the operational phase.

It is important to create a design process in which all the partners agree the goals of the project. How should the building be optimised? For example, should energy consumption be optimised per square metre, per working space, per person, or is the focus on finances, or some other aspect? How a construction client wants the building to be optimised should be clarified to the design team at the start of the process, thereby establishing a detailed framework that prevents optimisation being carried out individually by the different partners at a later stage.

The ideal is for construction and operating costs to be taken into account during both the design and construction phases. However, although this rationale is widely supported, the reality is somewhat different due to the constraints of financing, traditional planning and thinking, and for many other reasons. One reason is that only a few construction clients have the expertise and capacity necessary to monitor the process, thereby allowing them to influence the energy efficiency outcome at the design phase. In addition, the requirements are often set on the basis of the forecast energy consumption, rather than the actual amount of energy used in the completed building.

What role do the guidelines play?

Basically, the role of guidelines is to stimulate construction clients to get involved in the discussions that need to be taken before optimising the energy efficiency of a building. It is important to realise that energy efficiency does not happen in isolation. This is why it is crucial to design and create a strategy for the construction process that motivates all partners to make an active contribution to achieve an energy efficient result. Naturally, construction clients should be the most motivated, but their involvement alone is not enough to ensure that an energy efficient building results from the process.



Conclusion

Construction clients have a vested interest in energy efficiency, because this is the road to low operating costs in the completed building. However, clients often need help to manage the process.

Traditionally a client's interest in the energy consumption of the completed building represents only one element in a process that also includes other players whose interests in the outcome may be completely different. It is therefore important to evaluate how the energy operating costs of the completed building can be improved by all parties involved in the construction process. The Danish Energy Saving Trust's Construction Process Guidelines can help construction clients to navigate this process.

Organising who should be responsible for energy efficiency is also an essential part of the process. In this respect, the preferred solution often involves using the services of an independent energy evaluator. The evaluator should be in place from project start to assist with the drawing up of tenders and specifications. It is important that the construction client understands the significant opportunities that exist for establishing the requirements early in the pre-tendering phase. The opportunities for including cost-effective energy efficient solutions are much reduced once a tender has been accepted.

It is also important to agree on the method to be used when evaluating and comparing different solutions. Traditionally only investment costs are included. However operating costs should always be factored in. A comprehensive financial evaluation often leads to much better solutions in the long run.

Last but not least, the Construction Process Guidelines discuss different possible ways of organising an efficient process, with ideas and inspiration on how construction clients can derive the most benefit from the process.

The guidelines are developed for Denmark, but you can find an English translation on the webpage of the Danish Energy Saving Trust on this link: http://www.savingtrust.dk/publications/guidelines.

References

[1] Danish Energy Saving Trust. *Construction process guidelines*. ISBN 0978-87-92080-78-3 Denmark. 2009. link: http://www.savingtrust.dk/publications/guidelines

[2] Danish Knowledge Centre for energy efficient buildings. *Sådan fremmes energibesparelser i bygninger.* (How to improve the energy efficiency of buildings), Denmark. 2009.

Towards Low Carbon Office Building

Airaksinen Miimu

VTT Technical Research Centre of Finland

Abstract

In Europe the building sector accounts for a large part of the primary energy use, which results in CO_2 emission and a negative environmental impact. In the context of sustainable development, buildings should be constructed with adequate occupant comfort, limited natural resource use and low environmental impact, seen over the entire life cycle. Buildings itself are “problematic” since their production process is complicated, and the life span is long and the future phases are always based on assumptions. This paper studies a new office building in design phase and different alternatives to influence on the carbon foot print as well as the uncertainty of different assumptions and their effect on results in decision making in design phase. The calculations presented in this paper include building material, building process and energy use of the building.

Introduction

Buildings account for circa 40% of the total energy use in Europe [1] and for about 36% of the EU’s total CO2 emissions [2], including the existing energy conservation in buildings [3]. Even though energy saving measures at building level have been proposed, the net energy use at city/district level is still increasing. Buildings are important in achieving the EU’s energy savings target and to combat climate change while contributing to energy security. As the European strategic energy technology plan [4] states, strategies to improve energy efficiency at each level (energy conversion, supply and end-use) should be better imposed. In addition to the natural environment, the built environment has a large impact on the economy, health and productivity.

Key features of the Finnish energy policy are improved energy efficiency and increased use of renewable energy sources [5]. To achieve a sustainable shift in the energy system, a target set by the authorities, both energy savings and increased use of low-pollution energy sources are therefore priority areas. Building low-energy buildings, characterized by lower thermal energy demand than new buildings with ordinary energy standard, is in accordance with the declared national aim of reducing energy use. However, the use of electricity and domestic hot water will be of more importance to CO_2 emissions in the future.

The space heating demand of buildings has decreased by improved insulation, reduced air leakage and by heat recovery from ventilation air. However, these measures result in an increased use of materials. As the energy for building operation decreases, the relative importance of the energy used in the production phase increases and influences optimization aimed at minimizing the life cycle energy use. The life cycle primary energy use of buildings also depends on the energy supply systems.

Presently, the share of renewable energy used in the built environment is very modest; the renewable energy accounted for 10.3% of gross final energy consumption in the EU-27 in the year 2010 [6]. Both at national and international level, the targets for energy efficiency and share of renewable energy production imply a steep increase of intermittent renewable energy.

The use of a larger share of renewable energy compared to today’s levels with present day technology presents a number of challenges. Renewable energy supplies such as solar or wind energy have a fluctuating character, which is obviously problematic to the demand side: energy needs are usually rather constant or often not in the same temporal cycle as the supply. In addition the peak supply from renewable energies can be much higher than demand and the excess renewable energy cannot be stored. Especially in northern climates, the space needed for local renewable production (area of collectors, etc.) might become disproportionately large. Furthermore, the location of the buildings/districts is not always suitable for utilization of some renewable sources.

The ambition in sustainable development of the built environment is to reduce the harmful impact of the nature of materials and building energy use. Often the building energy use and the minimization of its CO_2 equivalent emissions are considered to be the desired goal. However, as the energy use decreases the importance of CO_2 equivalent emissions originating from building materials and products increases. Thus, what kind of materials and building products are used becomes more important. In addition, the minimization of CO_2 equivalent emissions is perhaps not the only desired target, but we need to consider also the minimization of primary energy use, since it highlights rather well the use of natural resources.

The aim of the study is first to find out the different available options to minimise energy consumption. Secondly the aim to consider the importance of CO2 equivalent emission from the embodied energy from building materials in respect to CO2 equivalent emissions from energy use in the building. Thirdly the aim is to find out how we should weight the primary energy use and the CO2 equivalent emissions of different options.

In this study is a real office building was studied. The building already had a rather compact quadratic shape, therefore the geometry is not a variable in this study.

2. Methods and studied buildings

The studied building is an office building located in Helsinki developed by Skanska Commercial Development Finland. The building was under design phase and the aim was to study different alternatives in order to choose the most energy and environmental efficient way to construct the building. The studied properties are shown in Table 1.

Table Studied design alternatives. The control systems include ventilation and lightning

Feature	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Building envelope excl. windows	Building Code 2010	Building Code 2010	Building Code 2010	Building Code 2010	Building Code 2010	Passive house
Windows (W/m^{2}K)	1.0	1.0	1.0	1.0	0.7	0.7
Ventilation heat recovery	70%	70%	80%	80%	90%	90%
LED lighting	in garage	in garage	in garage	in garage	in all spaces	in all spaces
Systems control level	building	room	room	building	room	room

In the 2010 Building Code the U-values for external walls is 0.17 W/m^{2}K, base floors 0.16 W/m^{2}K, roofs 0.09 W/m^{2}K and doors 1.0 W/m^{2}K. The ventilation heat recovery requirement in the 2010 Building Code is 45%, however in the calculations better heat recoveries were used, since that is the typical design option is studied cases. In the so called passive house level the U-values for external walls is 0.08 W/m^{2}K, base floors 0.15 W/m^{2}K, roofs 0.08 W/m^{2}K and doors 0.7 W/m^{2}K.

2.1 Calculation tools

The buildings were modelled in a dynamic IDA simulation environment [7, 8], where a RC-network (resistance-capacitance network) model of a building was used. The buildings were simplified to one zone models, and for users a typical profile according to Finnish energy calculation standards was used.

IDA is a modular simulation environment, which consists of a translator, solver, and modeller. The solver and physical models are separated, which makes it possible to change the mathematical formula of any component without changing the model description file. The modules are written in Neural Model Format (NMF), which serves at the same time as a readable document and a computer code. Via the translator, the modules can be used in several modular simulation environments [9, 10].

The embodied carbon in materials and material production process was calculated according to ISO 14020 and ISO14040 as well as ISO 14025. In addition the national method for building products and components were used [11]. Material specific environmental certificates and declarations were used.

2.2 Energy sources

The studied alternatives for energy sources and their CO_2 equivalent emissions are shown in Table 2. The average values in district heating and electricity refer to average values in Finland in year 2008.

Table 2 Primary energy factors and CO_2 equivalent emissions used

	Primary Energy Factor	CO_2 equivalent *
District heating average	1.87	0.22
District heating bio	0.4	0.12
Electricity average	1.87	0.38
Electricity from district heating average	1.87	0.38
Peak electricity from nuclear power	2.8	0
Peak electricity from coal	2.0	0.928
District cooling	0.25	0.12
Green electricity	0.2	0

* Unit: kg CO_2/kWh.

The service life for building was assumed to be 50 year. The embodied CO_2 equivalent emissions from building materials and process were estimated according to design drawings.

3. Results

3.1 Energy consumption

The energy consumption was 20% lower in case 6 compared to case 1. The only difference between case 3 and 4 was the control of temperatures. In the case 3 the control was at room level while in the case 4 the control was at building level. That resulted 7% difference in total energy consumption and 20% difference in space heating, in addition the difference in cooling was also 20% between those two cases, Figure 1.

Since in office buildings the electricity use has higher importance than heating, the case 6 does not have that much difference in consumptions even though the insulation values are much better (equal to passive house).

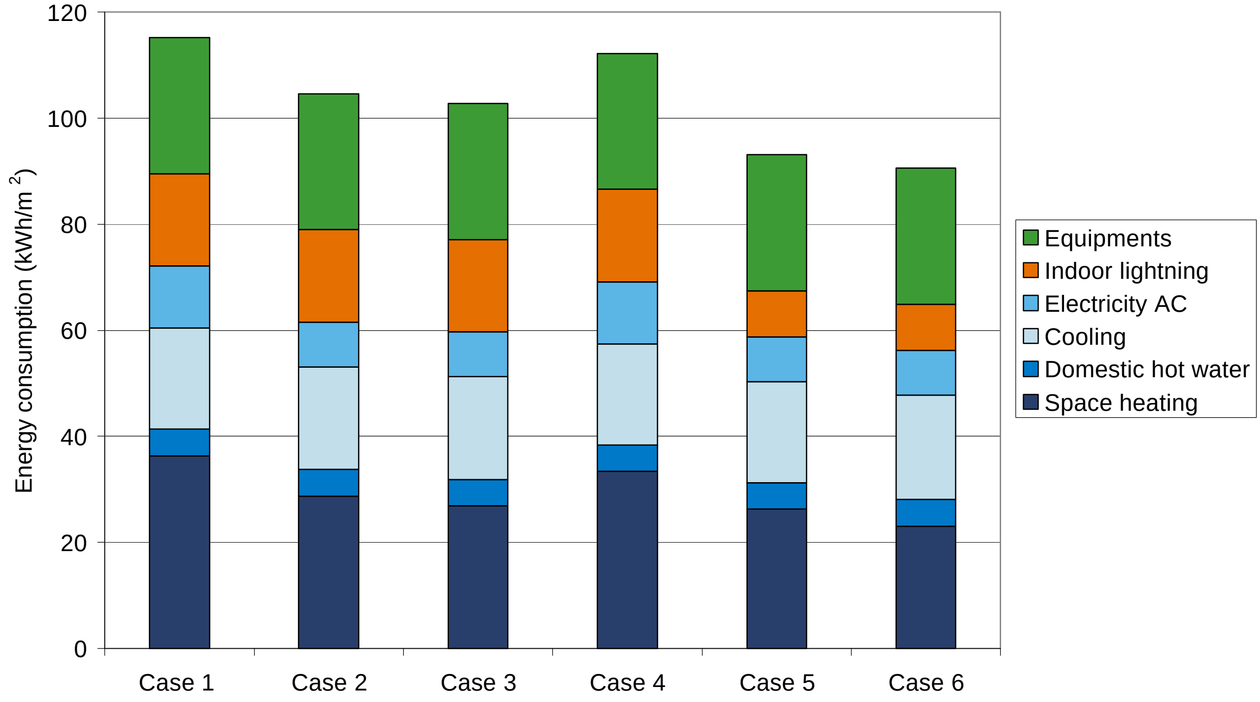


Figure 1 Yearly energy consumption in different cases.

3.2 CO_2 equivalent emissions

The Finnish Building code level U-values and ventilation heat recovery as well as air tightness of the building envelope are very good. This can be clearly seen from the energy consumptions (Figure 1) and CO_2 equivalent emissions, Figure 2. The embodied energy has already a high share for CO_2 emissions in addition to electricity. Basically in a typical office building the share of embodied CO_2 emissions are rather high being responsible of 30-40% of the total CO_2 emissions.

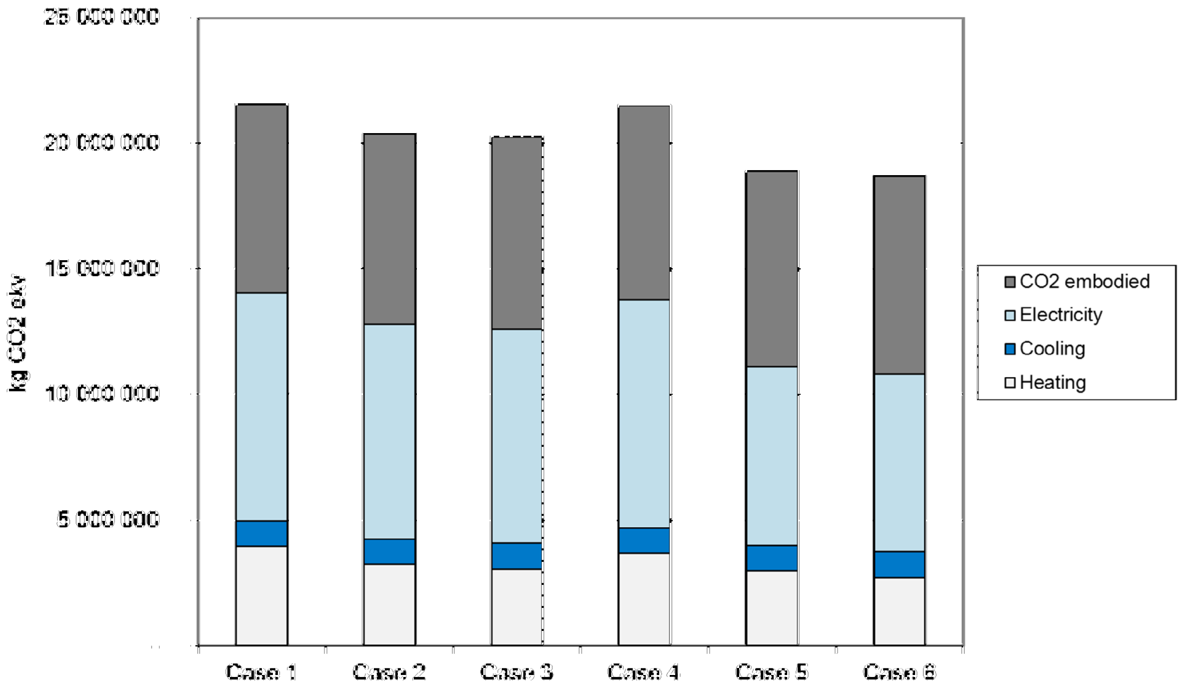


Figure 2 The share of each energy consumption and embodied CO_2 in different cases when average district heating, cooling and electricity is used.

Due to the low heating energy consumption the embodied CO_2 emissions and electricity are dominant components in the CO_2 emissions. That is actually rather surprising, since case 1 is the typical building code level in new office buildings, and only ventilation heat recovery is clearly better than the average in new buildings. In this study the embodied CO_2 includes energy consumption of building materials and products, and the use of raw materials and greenhouse gases.

Evidently, if all the electricity used is generated from renewable energy sources and for district heating and cooling bio-fuels are used, the embodied CO_2 emissions have the highest share and the over all CO_2 equivalent emissions decrease dramatically (Figure 3).

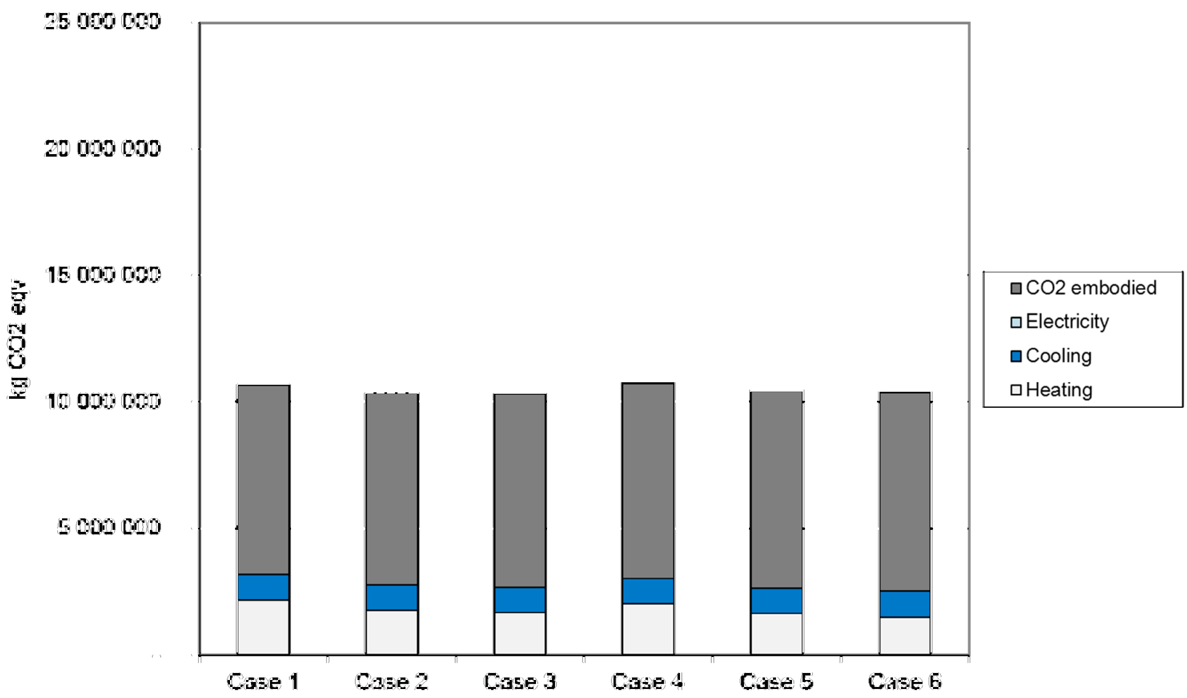


Figure 3 The share of each energy consumption and embodied CO_2 in different cases when district heating, cooling from bio fuels is used and electricity is from renewable energy sources.

Figure 4 shows the primary energy consumption as a function of the relation between embodied and energy-derived CO_2 equivalent emissions. The CO_2 equivalent embodied corresponds to the CO_2 equivalent emissions from materials during their lifetime and CO_2 energy corresponds the CO_2 emissions from energy use in the building (heating, cooling and electricity). When all different options for heating, cooling and electricity sources were compared it can be clearly seen that the nuclear-based energy alternatives all ended up with rather high primary energy consumption and since the building energy use is carbon neutral, the embodied CO_2 emissions become dominant (Figure 4).

If low primary energy is the target, then bio-based district heating systems seems to be effective as well as the use of electricity from renewable energy sources. Ground heat or the average local heating performed rather similarly in respect to primary energy use. This is because the ground heating systems use electricity but they can utilize the “free” thermal energy obtained from the ground. It can be seen that the local variations do have an effect on both primary energy use and CO_2 emission (Figures 2–4); in some parts the average Finnish values do have a good correlation to local energy production, but in some places the local production is closer to biomass-based production and in other locations closer to peak conditions (see Table 2). The lowest primary energy use is in alternatives based on bio local heating, cooling and green electricity. The lowest relation between CO_2 embodied and CO_2 energy in addition to low primary energy use was with the cases based on bio local heating, cooling and average electricity. When average electricity or nuclear energy based electricity was used, the energy saving was important and reduced primary energy use clearly. In bio based energy sources the energy saving measures were not that effective due to lower primary energy factors compared to nuclear energy.

The lowest primary energy was achieved when bio-based or renewable energies were used in addition to local heating and cooling. Obviously the highest primary energy was when nuclear power was used. When the primary energy use and CO_2 equivalent emissions are minimized the

CO_2 equivalent emissions originated from materials become rather dominant. In this study the CO_2 equivalent emissions originated from building materials and products is between 2.4 to 3.1 higher compared to CO_2 equivalent emissions originated from building energy use during running time when the building façade was non-wooden and the service life was 50 years.

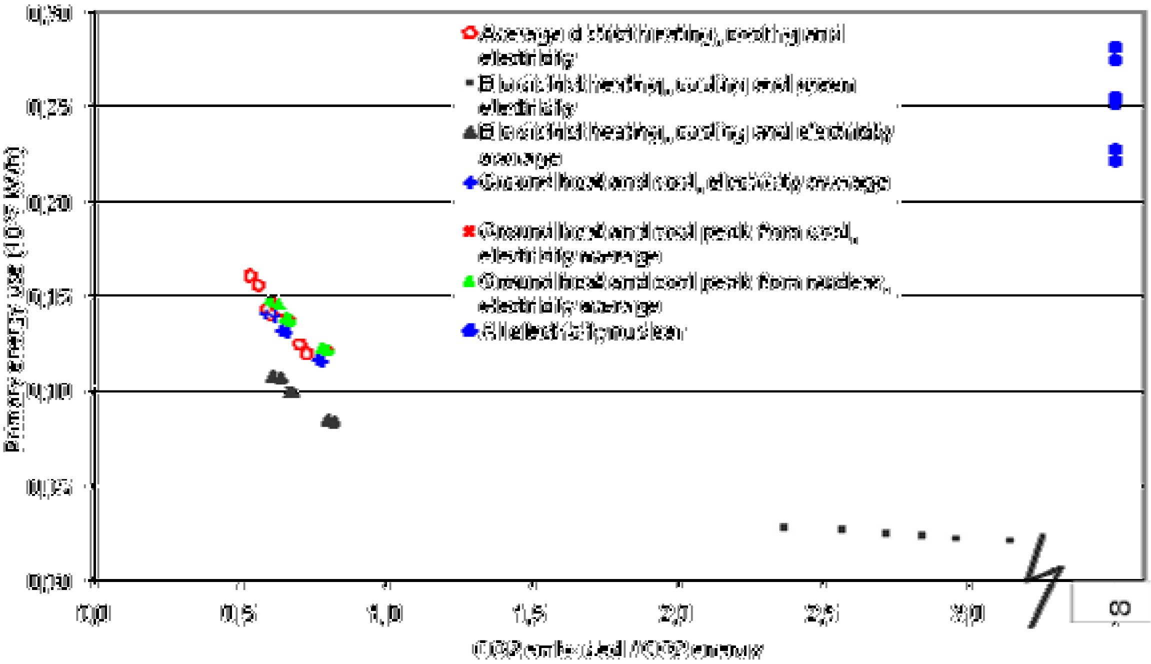


Figure 4 Primary energy consumption as a function of the relation between embodied and energy derivated CO_2 equivalent emissions. The CO_2 embodied corresponds to the CO_2 emissions from materials during their life time and CO_2 energy corresponds the CO_2 emissions from energy use in the building (heating, cooling and electricity). The time period used in calculations is 50 years.

3. Discussion

Finland is committed to the EU's 2020 targets which correspond to a 20% reduction in CO2 emissions compared to 1990 levels [12]. In addition, the Finnish Government has committed to cut down CO2 emissions by 80% by the year 2050 compared to the levels of 1990 [13].

The question is where we should target efforts to achieve these goals? At low CO_2 emission levels or low primary energy levels? The advantage of targeting low CO_2 levels, especially in energy consumption, is the fact that the CO_2 emissions are minimized, which is of course one of our major targets. However, considering only low CO_2 emissions in energy consumption still allows us consume rather high amounts of low CO_2 emitting energy [14]. Many low polluting energy sources, e.g., wood, are natural resources which we shouldn't waste. In addition the renewal period and the life cycle of the renewable energy source, must be considered as well. Hence low primary energy use should also be one of the priority targets since it reduces the use of natural resources.

Choosing the right energy source is a tricky question and is dependent on the location of the building. When only CO_2 emissions are considered, nuclear power has a strong position, but when primary energy considerations are taken into account nuclear power loses its advantage. Renewable energies are obviously strong alternatives. However, especially with wind and solar energy, the supply and demand of energy do not always match. Therefore both daily and seasonal storage are often needed. Bio-fuel based local heating and cooling seem to perform well, both in respect to primary energy use and CO_2 equivalent emissions, but there are big differences between average Finnish energy production and single power plants, e.g., the CO_2 equivalent emissions might nearly double depending on the energy source and power plant type.

According to this study a building with efficient local heating as a heat source, and a building with ground heat (nuclear power used for complimentary electricity source) performed very similarly in respect to CO_2 equivalent emissions. In Finland majority (75%) of district heating is generated in co-generation of heat and electricity. Therefore, if the use of local heating were to drop dramatically, the primary energy factor and CO_2 equivalent emissions from electricity would rise, leading to an increase of the emissions from the ground heat system.

When all different options were compared the nuclear-based energy alternatives all ended up with rather high primary energy consumption and since the building energy use is carbon neutral, the embodied CO_2 emissions become dominant. If low primary energy is the target then bio-based local heating systems seems to be effective as well as the use of electricity from renewable energy sources. Ground heat or the average local heating performed rather similarly in respect to primary energy use. This is because ground heating systems use electricity, but they can utilize the “free” thermal energy from the ground.

To target low CO_2 levels, especially in energy consumption, is obviously one of our major objectives, but considering only low CO_2 equivalent emissions in energy consumption might lead us to a wrong path; it does not limit our consumption of low CO_2 emitting energy. That is naturally not our target since low polluting energy sources such as wood, pellets and nuclear power energy are also natural resources which we should use with care. Setting low primary energy use as a target reduces the use of natural resources.

Problem in the yearly calculation is the the fact that we always exclude the energy match of supply and demand. However, that is very important both for energy security and CO_2 emissions. An example of that might be under dimensioned ground heat solutions used in buildings, which cannot be used on very cold days and need typically supportive power in those days. In respect to emissions, this can be problematic if the extra power supplied to markets is produced with a polluting energy source. On the other hand, in the buildings where cooling is needed, ground heat has the advantage that it can be used during cooling periods as well.

3. Conclusions

Current office buildings are becoming more and more energy efficient. Especially, while the importance of heating is decreasing, the share of electricity use is still increasing. When the CO2 equivalent emissions are considered, the CO_2 equivalent emissions from embodied energy have an important share, indicating that the building materials have a high importance which is often ignored when only the energy efficiency of running a building is considered.

Basically in a typical office building the share of embodied CO_2 emissions are rather high being responsible of 30-40% of the total CO_2 emissions. When the energy production is becoming more and more less CO_2 polluting the importance of embodied carbon in materials in increasing clearly.

The reduction of energy use reduces both the primary energy use and CO_2 emissions. The reduction of electricity use has especially high importance for both primary energy use and CO_2 equivalent emissions when fossil fuels are used. Often energy originated from fossil fuels is also used as a complimentary source of energy, thus the importance of reducing energy use and especially electricity originated from fossil sources has a high priority.

The lowest CO_2 equivalent emissions were achieved when bio-based, renewable energies or nuclear power was used to supply energy for the office building. Evidently then the share of CO_2 equivalent emissions from embodied energy from building materials and products became the dominant source for CO_2 emissions.

The lowest primary energy was achieved when bio-based local heating or renewable energies were used in addition to local cooling. Obviously the highest primary energy was when nuclear power was used. When the primary energy use and CO_2 equivalent emissions are minimized the CO_2 equivalent emissions originated from materials become rather dominant. In this study the CO_2 equivalent emissions originated from building materials and products is between 2.4 to 3.1 higher compared to CO_2 equivalent emissions originated from building energy use during running time when the building façade was non-wooden and the service life was 50 years. This paper did not study the effect of building geometry.

References

[1] EU Energy and Transport in Figures, Statistical Pocket Book 2007/2008; European Communities: Brussels, Belgium, 2008.

[2] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001: Mitigation; Third Assessment Report, Working Group III; IPCC: New York, NY, USA, 2001.

[3] Summary of the Impact Assessment; Communication Staff Working Document, Accompanying Document to the Proposal for a Recast of the Energy Performance of Buildings Directive (2002/91/EC); COM(2008) 755/SEC(2008) 2821; Commission of the European Communities: Brussels, Belgium, 2008.

[4] A European Strategic Energy Technology Plan (SET-PLAN); COM(2007) 723 Final; Commission of the European Communities: Brussels, Belgium, 2007. Available online: http://eur-lex.europa. eu/LexUriServ/LexUriServ.do?uri=COM:2007:0723:FIN:EN:PDF (accessed on 22 November 2007).

[5] Finnish Ministry of Environment. Permits Related to Land Use and Building. Available online: http://www.ymparisto.fi/default.asp?node=19665&lan=en (accessed on 17 August 2011).

[6] Eurostat Renewable Energy Statistics; Statistics in Focus—56/2010, Eurostat: Luxembourg, Belgium. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-10-056/EN/KS-SF-10-056-EN.PDF (accessed on 17 August 2011).

[7] IDA Simulation Environment. Available online: www.equa.se (accessed on 5 May 2011).

[8] Sahlin, P.; Grozman, P. IDA Simulation Environment—A Tool for Modelica Based End-User Application Deployment. In Proceedings of the 3rd International Modelica Conference, Linköping, Sweden, 3–4 November 2003.

[9] Sahlin, P. Modelling and Simulation Methods for Modular Continuous Systems in Buildings. Ph.D. Thesis, Royal Institute of Technology: Stockholm, Sweden, 1996.

[10] Sahlin, P.; Bring, A. IDA Solver—A Tool for Building and Energy Systems Simulation. In Proceedings of the BEPAC Conference “BEP’91”, Nice, France, 14–19 August 1991; pp. 576–582.

[11] Voimassa Olevat RT-Ympäristöselosteet; Rakennustietosäätiö RTS: Helsinki, Finland. Available online: http://www.rts.fi/ymparistoseloste/voimassaolevatympselosteet.htm (accessed on 17 August 2011).

[12] The EU Climate and Energy Package; European Communities: Brussels, Belgium. Available online: http://ec.europa.eu/clima/policies/package/index_en.htm (accessed on 5 May 2011).

[13] The Future of Finnish Climate and Energy Policy; Finnish Government: Helsinki, Finnish, June 2009. Available online: http://www.valtioneuvosto.fi/toiminta/tulevaisuusselonteko/fi.jsp (accessed on 5 May 2011).

[14] Johansson, P.; Nylander, A.; Johnsson, F. Primary energy use for heating in the Swedish building sector—Current trends and proposed target. Energy Policy 2007, 35, 1386–1404.

Building Communities: Organizational Culture, Energy-Efficiency Adoption, and Occupant Behaviour in Tenanted Commercial Property

Kathryn B. Janda[1]

Environmental Change Institute, University of Oxford, Oxford, UK

Abstract

Axon et al. [1] argue that reducing energy use in tenanted commercial property requires greater understanding of buildings as "communities of practice" in order to maximise the potential for energy efficiency and demand reduction. This paper extends the "building communities" framework by examining the literature underpinning the relationship between organizational culture, energy-efficiency adoption, and occupant behaviours. The paper begins by reviewing the literature on stakeholder engagement and characterizing ways of understanding the relationships between people, energy and buildings. This literature tends to address either organizational choices, or occupant engagement, but it rarely crosses the analytical boundaries between these two groups. The paper explores these different types of behaviour within a 3C's-- "concern, capacity, and conditions"-- framework. The combination of these two frames reveals a gap or grey area between organizational culture, occupant behaviour, and technology adoption where further conservation opportunities may lie. In conclusion, the paper argues that the concept of a building community is useful in characterizing both the organizational cultures and individual behaviours that influence the adoption (and rejection) of energy efficiency strategies within tenanted and owner-occupied commercial properties.

Keywords: community, energy management, occupant behaviour, organizational culture, refurbishment, commercial buildings

Introduction

The UK non-domestic stock plays a significant role in contributing to carbon emissions, representing about 18% of the total [2]. Increased legislative requirements in the investment property market, together with an increased emphasis on the sustainability agenda from both landlords and tenants, have led to an added impetus to improve the environmental performance of buildings. During 2008, the Climate Change Act called for an 80% reduction on 1990 UK carbon emission levels by 2050, a target which is now legally binding. This goal is now underpinned by the Carbon Reduction Commitment Energy Efficiency Scheme (CRC) and the Green Deal. The transposition of the European Union Energy Performance in Buildings Directive (EPBD) and its recast to the UK means that energy performance of buildings is at the forefront of visible legal requirements, building regulations, and professional guidance. Finally, there is a current government target to achieve zero carbon in all new non-domestic buildings by 2011 [3].

Recent research has shown an emerging and increasing demand for sustainable offices by corporate occupiers [4] and similar findings have emerged from both the USA and Australia [5, 6] This is being driven not only by legislation but also by the perceived cost advantages that more energy-efficient commercial property can offer tenants and the potential for increased rentals for landlords [see for example, 4, 6, 7, 8]. This has also been driven by changes in corporate attitudes towards

---

[1] Portions of this paper draw upon work in progress on "Building Communities" jointly prepared by: the author and: S Bright, Oxford University; T. Dixon, Oxford-Brookes University; C. Axon, Brunel University; M. Kolokotroni, Brunel University.

environmental issues and sustainability, with many companies now recognising the commercial benefits of sustainable business practices and processes. This has been characterised by leading companies competing to be seen as ‘the greenest’ in response to legislation aimed at reducing carbon footprints; increased public pressure; the development of new business opportunities; and the shift towards greater corporate accountability. This is also because many companies have recognised the benefits of ‘going green’, driven by the desire to highlight corporate social responsibility (CSR) credentials [9-11].

Despite the overall policy and practical interest in improving buildings, there is much work to be done. A recent global survey of 700 listed property companies and fund managers revealed that the majority of the companies surveyed are not yet actively managing environmental issues in their property portfolio [12]. Although techniques and technologies could cut existing buildings’ consumption substantially, overall refurbishment rates remain low and a range of barriers to energy efficient buildings need to be overcome [13].

Approximately half of the total UK stock of ‘core’ commercial buildings (shops, offices and industrial premises) is occupied by tenants [14]. Given that it is much more difficult in logistical terms to reduce the energy use in commercial buildings that are occupied by tenants than owner-occupied spaces, there is a clear need to identify effective and coherent ways to maximise energy reduction in tenanted commercial space. To reduce energy use in commercial buildings it is necessary to increase technical energy efficiency through the design and refurbishment process, and concurrently, manage building energy services and expectations in a coordinated, complimentary way, while negotiating a change in the traditionally adversarial relationship between tenant and landlord. This requires an ‘interdisciplinary’ understanding not only of engineering science to know what is technically possible within the building, but also social science to understand the variety of factors that impact the way that landlords lease and tenants occupy and use that space.

Although closing the gap between an existing commercial building’s technical potential and its resource use in practice is a complex and multi-layered problem that requires both technical and social solutions, research worldwide has often followed a physical, technical, and economic approach to increasing the level of energy performance in the building sector [15]. Social and institutional factors have been understudied relative to technologies, yet they hold the key to significant market transformation in practice [16]. This problem is heightened by the diverse and complex nature of the different stakeholders involved [2]. Landlords, agents, facilities managers, tenants, building services companies, and users all have different levels of interest, investment, and control over such changes. This means that the whole community of users must be engaged in the performance upgrade process, and in particular it requires the landlord and tenant relationship to work in a way that promotes clearly defined environmental objectives.

This paper considers sociotechnical problems and potential solutions in improving existing tenanted commercial properties. New build has received much attention but as it represents only 1-2% of total stock, transforming the energy efficiency of existing property remains crucial and presents greater challenges [4]. The paper concentrates on energy use, but the arguments are similar for other environmental impacts. This research agenda is internationally relevant; although we highlight practices in the UK, and there are differences in detail in the property and letting practices of the major developed nations, the issues they face are similar, and both those owning and renting commercial spaces are often international players.

The paper begins by reviewing the literature on stakeholder engagement, discussing several frames for understanding the relationships between people, energy and buildings. This literature tends to address either organizational choices, or occupant engagement, but it rarely crosses the analytical boundaries between these two groups. To consider the intersection of these different types of behaviour, the paper employs two analytical frames: a “building communities” framework and a “concern, capacity, and conditions” framework. The paper uses the combination of these two frames to shed light on energy efficiency opportunities at the intersection of organizational culture, occupant behaviour, and technology adoption. In conclusion, the paper argues that the larger concept of a building community is useful in characterizing the organizational cultures, individual behaviours, and workplace practices that influence the adoption (and rejection) of energy efficiency strategies within both tenanted and owner-occupied commercial properties.

Background

A key challenge to the transformation of energy efficiency and demand reduction in the tenanted commercial built environment is to understand and tackle the complexity that stems from the interrelationship of:

i. the range and variety of commercial building stock (age, condition, use etc);

ii. the number of stakeholders – investors, developers, agents, owners, tenants, facilities managers, and users of the space (employees and customers) – as well as the fragmentation within and across these groups

iii. traditional leasehold structures and language.

This paper focuses in particular on the stakeholders (ii) and their relationship with the physical space they occupy (i), so it is applicable to both tenanted and owner-occupied spaces. However, it recognizes the critical importance of the lease (iii) in tenanted properties. In any particular tenanted space the opportunity for environmental change is mediated (hindered or enabled) through the lease. In addition to being an important legal document that frames who is responsible for what, the process of creating a different kind of lease (e.g., a "green" lease) has been shown to foster useful communication between tenants as well as between tenants and landlords [17]. A full discussion of this issue is beyond the scope of this paper, but has been taken up elsewhere [e.g., 18].

Several different approaches have addressed various elements of this set of nested problems from a stakeholder engagement perspective. Melton [19] suggests that successful engagement needs to include designers, transform social norms, and provide sufficient incentives. Other work has focused on the diversity of stakeholders. A recent special issue of Building Research and Information (Volume 39, Issue 5, 2011) recognised and investigated the importance of stakeholder groups in producing (or inhibiting) environmental changes in the building industry. Nishida and Hua (2011) call attention to the importance of engaging stakeholders in programme design and its introduction. Lützkendorf, Fan, & Lorenz (2011: 496) show how diversity within financial stakeholders leads to a need for "new forms of cooperation and information exchange." Although there are many different types of stakeholders involved in commercial properties, two of the main strands of the engagement literature involve research related to (1) occupants and their behaviour, or (2) organizations and their behaviour.

Occupant Behaviour – Acting Efficiently

Researchers in domestic buildings have long been aware that different inhabitants can use the similar buildings very differently, with enormous variations in energy use [20]. This leads to the conclusion that buildings don't use energy, people do [21]. The same principle applies in non-domestic settings. Competitions in university dormitories [22] and programs in public sector and office buildings [23] have shown that there are at least short term gains to be made by inducing occupants to change the way they use technologies and spaces.

However, there are seldom established mechanisms for ensuring that the community of persons using a particular space do so efficiently. Tiedemann, Sulyma [24] surveyed 279 business customers about lighting, air conditioning, and heating behaviours. Although approximately half of those surveyed had the ability to take conservation actions, a smaller percentage of the respondents actually perform the actions. In the case of lighting, for instance, 52% of the respondents had the ability to turn off lights in unoccupied spaces, but only 39% actually reported doing so always or often. Moreover, there are hidden costs of adopting more efficient energy equipment, such as learning how to use equipment "properly" (i.e., in the way designers intended).

Individual "behavior" studies, whether in residential or commercial buildings, tend to only assess actions that individuals can control. This view tries to separate actions from the context in which they occur. In contrast, this paper sees such actions as embedded in a social and technical context. Different tenant organisations will place different emphasis on the importance of environmental performance, as will different landlords. So employee behaviours are couched within the guidelines and limits of their jobs, which are set by the organizations for which they work, and are further conscribed by the premises in which they perform their duties.

Organizational Culture – Adopting and Managing Efficiency

Organizational culture is a term often used to define a set of rules and behaviours nurtured by and within a particular company, firm or institution. It is widely recognized in the organizational behaviour and public choice literatures that organizations, firms, and social groups do not behave like individuals. Instead, they exhibit their own dynamics that may contribute to the low level of energy efficiency implementation [25-28].

The extent to which energy is "seen" as a problem by senior management in most firms is unclear. Although energy efficiency investments and practices are cost-effective, they are often not pursued; energy is often seen as peripheral to the strategic goals of firms and other investments are seen as having higher priority or profitability [29]. Energy visibility, as both a technical and organisational issue, is therefore a key factor in improving building performance. It is often assumed that there is an energy manager who sees, monitors and manages energy use but, depending on the size, composition, and interests of the organisation, this management function may be served by no one, one person, an entire team, or even moved offsite [30-32]. Across different organizations, therefore, technical and organisational abilities to incorporate and respond to energy issues vary.

The "3Cs" framework operationalizes this idea by suggesting that energy efficiency and conservation actions in organisations depend on the level of "concern" within the organisation about efficiency relative to other business goals; the "capacity" of the organisation to take action; and the real-world physical and technical "conditions" of the premises that are to be acted upon [30, 31]. The presence or absence of these three variables can be used to recognise variation within organisations and potentially map different policy approaches to encourage energy efficiency or conservation (see Table 1 below). This characterization also suggests that there is not one kind of firm; there may be at least eight different kinds. Each of these kinds of firms could need a different kind of incentive to strive for higher levels of efficiency.

Table 1. Policy Implications of Variation in "Concern, Conditions, and Capacity"(3Cs)

Concern Concern about energy	**Conditions** Opportunities for conservation	**Capacity** Ability to act on opportunities	**Policy approach to increasing energy efficiency (EE)**	Speculation about whether price increases might encourage (+) or discourage (-) conservation action
Yes	Yes	Yes	Recognize/Encourage EE	+
Yes	No	Yes	Recognize past EE, create future opportunities	+
Yes	Yes	No	Technical assistance, incentives, peer support, education	+
Yes	No	No	Technical assistance, peer support, education, create future opportunities	+/–
No	Yes	Yes	Incentives, non-energy benefits, recognize past EE	+/–
No	No	Yes	Support continuous improvement, identify non-energy benefits, recognize past EE	–
No	Yes	No	Technology assistance, incentives, peer support	–
No	No	No	Mandatory efficiency standards	–

Source: Janda, Payne, Kunkle & Lutzenhiser [31]

As shown above, this framework was originally employed as a set of binary variables related to the state of the organization at the time of the research. Organizations either did or did not have concerns about energy; did or did not have conservation opportunities; did or did not take action on these opportunities. As the research was based on short term crisis response to possible blackouts at a specific point in time, this simple approach seemed appropriate. However, in the process of the research and development of the framework, other questions arose. For example, over time, can one kind of organization turn into another kind of organization? What are the underlying factors that lead to these different observed "states"? These questions will be explored in the following section.

Building Communities and Communities of Practice

Analytically, studying either employees or organizations makes disciplinary sense. However, from an energy reduction perspective, combining these approaches may lead to additional opportunities that would be inaccessible through either lens on its own.

To understand how to maximise the opportunities that exist to improve the energy performance of the commercial built environment, Axon et al. [1] argue that new interdisciplinary research is needed. These authors propose a "building communities" framework that accommodates the perspectives of all the actors, the physical context in which they interact, as well as the legal, policy, and market frameworks that shape their interactions.

Axon et al.'s concept of community is built around the idea of "communities of practice" (CoP) [33, 34]. A CoP is a system of relationships between people, activities and their outside world developing over time and interconnected with other CoPs, which themselves can be found within businesses, across businesses and other organisational and professional structures [35, 36]. The concept of CoP also has implications for knowledge management and its codification [37]. Such communities can be either geographically coherent and organisationally diverse (e.g., a multi-tenanted office building or shopping mall); or organisationally coherent and geographically diverse (e.g., a fleet of Marks & Spencer stores). As shown in Figure 1, these communities are at the core of three interlocking themes and can be investigated through three cross-cutting levels of analysis. The themes included in Axon et al.'s research are (1) legal and property aspects of improving energy performance; (2) policy context and organisational response; and (3) technology adoption and environmental performance. The levels of analysis recognize that building communities are affected simultaneously by the general context in which the community is situated (e.g. the building standards and resource costs in a particular country); company-level expectations and building-level specifics.

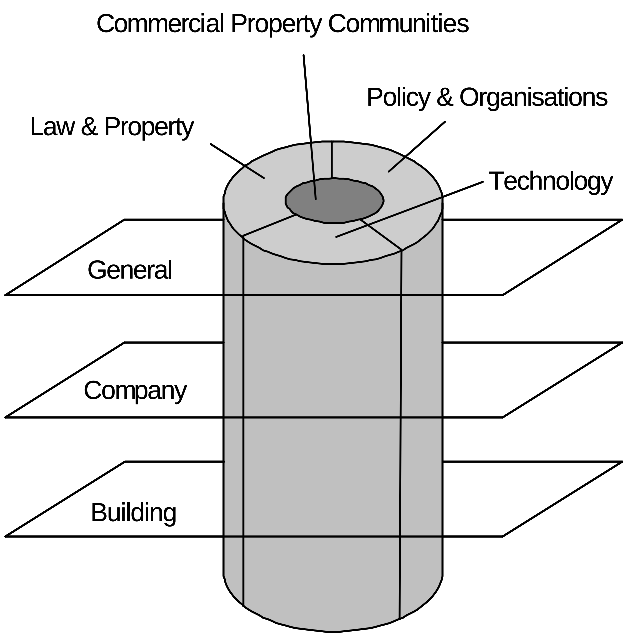


Figure 1

A conceptual framework of issues affecting commercial property communities [1].

One benefit of a "building communities" frame is that it moves beyond the usual levels of analysis that tend to take account of either "organizations" or "users." It recognizes that employees are both a part of and apart from the organization in which they work. Employees have to do their jobs, but in many office contexts, they have some agency over their actions that their employers do not completely control. Organizations govern some, but not all, of the actions their employees take, and the expectations that they have about their work practices. Similarly, organizations are a part of and apart from a larger market and social context for the goods and services they are providing.

Cross-Cutting Frameworks: 3Cs and Communities

To conceptually explore the grey area that lies between and around organization and employee interactions, we have augmented the "3Cs" framework introduced earlier and used it to consider the two different analytical levels commonly used in "behaviour" studies. Table 2 shows an overlay of the intersection of these two frameworks. Because the complexity of the framework has increased, the direct policy and economic implications suggested in Table 1 have been removed. Wrapped around these two frames is the concept of "building communities" which includes (but is not limited to) both organizational and individual analytical levels.

Table 2: A "Building Communities" view of 3Cs and behavioural research

		3Cs		
	Analytical Level	**Concern** (factors that shape attention to energy)	**Conditions** (factors that shape where energy actions occur)	**Capacity** (factors that moderate abilities to take energy actions)
Building Communities (grey area, neither organizational nor individual)				
	Organization	Legislative requirements, leases	Building retrofit opportunities, thermostat setpoints, standard operational hours, provision of space & equipment	Energy management structure; job titles & responsibilities; feedback & data availability; granularity of data
		Workstyles	Clothing choices, activities outside "normal" hours	Peer pressure & social practices; workgroup dynamics
	Individual	Attitudes, beliefs, habits, values	Use of task lights, computers, auxiliary heating/cooling devices; extra plug loads; operation of blinds / windows	Presence or absence of champions; expertise & understanding of systems; interest in and ability to act on feedback

The overlay of these frameworks serves four purposes. The first purpose is to move beyond the binary "states" used in the original 3C's framework to call attention to factors that may shape these states at different analytical levels. The second purpose is to introduce a question about the relationship between "organizational" and "individual" levels of analysis. The third purpose of the overlay is to suggest that there is a grey area between the organizational and behavioural levels of analysis that is (a) not well understood, and (b) capable of affecting the interrelationship of organizational aims and individual actions. The fourth purpose is to suggest that a "building communities" approach might help knit together the organizational and individual levels by looking above, below, and between them. Each purpose is discussed in turn below.

Factors Shaping 3Cs: Individual and Organizational Aspects

In its original application, the 3Cs framework was conceptualized as a binary set of variables, where concern, physical conditions, and capacity were either present or absent. This paper augments this framework by considering in a bit more detail how these variables are constructed and operationalized at the individual and organizational levels. For example, organizational concern about energy may be more directly affected by leases and legislative requirements, which tend to be aimed at the organization, not the employee. Employee concern may be more affected by personal attitudes, practices, habits, and beliefs than organizational concern. Similarly, the physical and technical conditions of energy actions are different at the level of the organization and the individual employee. Individual employees may have a modicum of control over the space in which they work and the machines they use to do their job, but unless they are the building manager they rarely have any say in ordering full scale building retrofits. In terms of the capacity to take energy actions, the organization creates job descriptions, staffing levels and employee responsibilities. It decides how (in principle) energy issues relate to the core business of the organization, and whether it is seen as a simple cost, a risk, an investment, a public relations concern, or some combination of the above. It may also decide how much energy data to gather, to reveal, and to whom. Individual employees may have some ability to influence organizational energy actions by taking on additional responsibilities – such as being a "champion" for energy – or by reacting appropriately to organizational cues to use their workplaces "correctly." They can also ignore, change, or subvert such exhortations by amending spaces to suit their tastes and comfort levels.

Targeting the organization and/or individual

The discussion above leads to a second purpose of examining these frameworks in tandem, which is to introduce a question about the relationship between "organizational" and "individual" levels of analysis for energy programs. Should they be separate efforts, or integrated? If they are connected, how tightly are they coupled, and in what ways?

Not surprisingly, programs that integrate technical and behavioural strategies have greater levels of savings than programs that concentrate solely on behaviour. Bin [23, p. 11] found that a comprehensive project targeting sustainability in the workplace through technical and behavioural strategies resulted in a 74% savings in carbon emissions. In contrast two "behavior-only" programs that aimed to create a "culture of conservation" resulted in a 5% electricity savings in one case and a 4.2% energy savings in the other. Importantly, the behaviors addressed in these projects were at the individual employee level. Upper management in all of the organizations made public pledges to reduce energy use, but only in one project did senior management actually participate in meetings and serve on committees to think about energy use. This proactive organization happened to BC Hydro, for which energy is already a core part of the business.

These results might tempt the reader to forget about behaviours and focus on technologies. Since proactive employee behaviours only provide savings on the order of 4 or 5%, and programs that include technologies can save much more, is it even worthwhile to address how employees use the spaces and technologies around them?

It is appealing to believe it is possible to draw clear distinctions between technology adoption, organizational culture, and occupant behaviour. However, in reality, these boundaries are blurred. Technologies are not adopted in a vacuum; they are generally "adopted" at the organizational level (e.g., someone in the management company decides to upgrade the HVAC equipment). But technological adoption is in itself a behavior, because technologies don't actually adopt themselves (except in engineering-economic models). So the relationship between technology adoption and organizational culture may be iterative and ongoing, or it may be fixed and static, but these two factors are definitely intertwined.

Similarly, occupant behavior shapes and is shaped by organizational culture. For example, the kind of person who gets on well at a blue chip firm where the partners play golf might not fit in as well at an internet startup where employees are more likely to play World of Warcraft. Workplace cultures are, to a greater or lesser extent, co-constructed over time by both organizations and employees. It stands to reason that energy practices and technology uses may also be co-constructed in a similar fashion. Some examples are given in the next two sections.

Grey Areas: Between and Around Organizations & Individuals

The third purpose of overlaying the 3Cs and behavioural research strands is to demonstrate that there is a grey area between the organizational and behavioural levels of analysis that is (a) not well understood, and (b) capable of affecting the interrelationship of organizational aims and individual actions.

Consider, for example, the complex interrelationship of thermal comfort, clothing, and work practices. In many cases, employees choose what is appropriate garb for the work that they do, based upon established social practices as well as some measure of personal preference. A businessman may know he is expected to wear a tie, long-sleeved shirt, and a jacket to an important meeting, even though it is a hot day and he will be uncomfortable outside. The individual might prefer to wear shorts and a T-shirt, but he knows everyone else in the meeting will be wearing a business suit and his boss will expect him to dress appropriately. Importantly, the location where the meeting will be held will be air-conditioned to account for the comfort of the people wearing suits. This is business as usual, and most "behaviour" programs operate within the parameters established by common practices, rather than attempting to question or change them.

Recognizing that common practices have energy implications, and thinking about steps to change them, is a grey area in the literature. A string of mutually co-constructed practices that affect the way work occurs is very difficult to change through a program aimed at exclusively either technical, or organizational, or behavioural energy efficiency actions.

A Building Communities Approach

Although it may be difficult to change established practices in particular ways, it is not impossible. Or, more specifically, it is not impossible if the change strategy addresses the underlying social relationships that shape the practice. The Japanese "Cool Biz" program, for example, aimed to reduce air conditioning loads by changing social expectations around appropriate clothing for business meetings [38]. Ministers modeled short sleeves and eschewed ties, and thermostats were set to a new norm of 28 degrees C. In 2011, the Japanese government introduced "Super Cool Biz", which included ideas like extending the summer vacation by a week, shifting to a work day that starts earlier, and even wearing untucked polo shirts to work [39]. Is there more room for change in this grey area, where organizations and employees shape and are shaped by common practices and workstyles, that are to some extent between and beyond them?

Instead of focusing on technologies or organizations or employees, a "building communities" approach simultaneously addresses all three of these analytical levels. This multi-level approach cultivates understanding of these levels, as well as enabling a glimpse of the issues between and beyond them. As targets for carbon emission reductions ratchet up from capturing "low-hanging fruit" to achieving "zero-carbon", interstitial and underlying social issues may become more important than originally thought. Like reducing standby losses, they may require further attention and, eventually, offer additional opportunities for reducing energy use and improving building performance and occupant satisfaction.

Take, for example, the case of building uses outside of "normal" operating hours. Employees working late or on weekends, or holding events after hours can affect the expected energy profile of a building. Sometimes these uses are officially sanctioned. "Flex time" is a popular program in some organizations that allows workers shift their working hours to better accommodate their personal needs. Sometimes, however, these uses are separate and additional to normal work. For example, a high profile low-energy green campus building with a lovely atrium turned out to be an attractive location to host concerts, formal dinners (with catering), conferences, workshops, and even a wedding. The initial occupancy schedule, used in the building's energy model, included only the building's official and normal functions: as classrooms and offices [40]. The additional (non-modeled) usages increased the building's energy consumption, but also increased its social benefits. Musicians liked its acoustics; the college enjoyed treating potential donors to special events in a famous space. Organizations may not explicitly condone such practices, or they may foster them, but it is important to recognize that buildings may serve a larger number of people in different ways than an energy perspective usually incorporates.

The relationship that develops between the building and its community of users is a topic of interest in environmental design research, but curiously, not in energy research. How could or should these non-work or beyond-work building uses be incorporated in building models, planned for in organizational strategies, and handled in terms of design? Could this interest in using a building for non-work purposes be fostered and channeled into higher levels of user engagement? If energy researchers understood how different combinations of people and organisations use spaces, could they help these buildings perform better instead of worse?

Summary and Conclusions

Previous research has recognized that organisational cultures and individual actions affect the ability of the non-domestic sector to engage with energy efficiency strategies. This paper has argued that improving energy efficiency in tenanted commercial buildings requires an interdisciplinary 'whole systems' understanding of 'community-based' practices. The ownership, management, and occupation of commercial properties are usually divided between different entities which need to work together for the full savings to be achieved. The ability to create environmental synergies across property fleets and within individual buildings is the key; the factors at the organisational level that promote or inhibit the greater uptake of energy saving technologies and practices, as well as the division of responsibilities surrounding decisions to enact change are areas on which new research needs to concentrate. Many organisations are now global players, and although there may be specific localised environmental challenges and policies, the opportunity for learning through shared experiences and communities of practice is an international one.

Previous research in the field of commercial property has neither been able to address how new technologies can be and are deployed in practice to improve energy performance, nor to analyse the socio-technical frameworks that underpin these measures in sufficient detail. Therefore, there is an urgent need for new research which brings together law, property, social science, and engineering to examine the nature of the existing relationships between landlord and tenant communities. We need to understand how organisations develop and implement company-wide environmental policies so that energy management is practiced not only within specific physical spaces but across a geographically diverse portfolio of properties. This also provides opportunities for shared learning.

References

[1] Axon, C.J., S.J. Bright, T.J. Dixon, et al., *Building Communities: Why We Need a New Interdisciplinary Approach to Reducing Energy Use in Tenanted Commercial Property.* Building Research & Information, 2012. Special issue on building research (forthcoming).

[2] Carbon Trust, *Building the Future, Today*, 2009, Carbon Trust: London.

[3] DCLG, *Zero Carbon for New Non-Domestic Buildings: Consultation*, 2009, Department of Communities and Local Government: London.

[4] Dixon, T., G. Ennis-Reynolds, C. Roberts, et al., *Is there a demand for sustainable offices? An analysis of UK business occupier moves (2006-2008).* Journal of Property Research, 2009. **26**(1): p. 61 - 85.

[5] Newell, G., *The Strategic Significance of Environmental Sustainability by Australian-listed Property Trusts.* Journal of Property Investment & Finance, 2008. **26**(6): p. 522-540.

[6] Eichholtz, P., N. Kok, and J. Quigley, *Why Do Companies Rent Green? Real Property and Corporate Social Responsibility*, in *Energy Policy and Economics*2009, University of California Energy Institute: Berkeley.

[7] Kats, G., L. Alevantis, A. Berman, et al., *The costs and financial benefits of green buildings: A report to Californiaís sustainable building task force.* Capital E, Washington DC, 2003.

[8] Fuerst, F. and P. McAllister, *Does it pay to be green? Connecting economic and environmental performance in commercial real estate markets.*, 2008.

[9] Pivo, G. and P. McNamara, *Responsible Property Investing.* International Real Estate Review, 2005. **8**(1): p. 128-143.

[10] Nelson, A., *Globalization and Global Trends in Green Real Estate Investment*, 2008, RREEF Research: San Francisco, CA.

[11] Pivo, G., *Responsible property investment criteria developed using the Delphi Method.* Building Research & Information, 2008. **36**(1): p. 20-36.

[12] Kok, N., P. Eichholtz, R. Bauer, et al., *Environmental Performance: A Global Perspective on Commercial Real Estate*, 2010, European Centre for Corporate Engagement, Maastricht University School of Business and Economics: Maastricht.

[13] European Commission, *Energy Efficiency Plan 2011*, in *Communication 109*2011: Brussels, Belgium.

[14] Dixon, T., *Urban land and property ownership patterns in the UK: trends and forces for change.* Land Use Policy, 2009. **26**(Supplement 1): p. S43-S53.

[15] Lutzenhiser, L., *Social and Behavioral Aspects of Energy Use.* Annual Review of Energy and the Environment, 1993. **18**: p. 247-89.

[16] Biggart, N.W. and L. Lutzenhiser, *Economic Sociology and the Social Problem of Energy Inefficiency.* American Behavioral Scientist, 2007. **50**(8): p. 1070-1087.

[17] Langley, A., L. Hopkinson, and V. Stevenson. *Green Leases; An opportunity to develop a sustainable approach for Tenanted Commercial Buildings in the UK*. in *Fifth International Conference Proceedings for the International Energy Efficiency in Commercial Buildings (IEECB) conference*. 2008. Frankfurt, Germany.

[18] Hinnells, M., S. Bright, A. Langley, et al., *The greening of commercial leases.* Journal of Property Investment & Finance, 2008. **26**(6): p. 541-551.

[19] Melton, P., *Occupant Engagement-Where Design Meets Performance*, in *Environmental Building News*2011, BuildingGeen: Vermont, USA.

[20] Socolow, R., *Saving Energy in the Home: Princeton's Experiments at Twin Rivers*1978, Cambridge: Ballinger.

[21] Janda, K.B., *Buildings Don't Use Energy: People Do.* Architectural Science Review, 2011. **54**(1): p. 15-22.

[22] Petersen, J.E., V. Shunturov, K.B. Janda, et al., *Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives.* International Journal of Sustainability in Higher Education, 2007. **8**(1): p. 16-33.

[23] Bin, S., *Greening Work Styles: An Analysis of Energy Behavior Programs in the Workplace*, 2012, American Council for an Energy-Efficient Economy: Washington DC.

[24] Tiedemann, K., I. Sulyma, R. Sahota, et al. *Behavior and Potential Energy Savings in Business Establishments*. in *ACEEE Summer Study on Energy Efficiency in Buildings*. 2008. Asilomar, CA: American Council for an Energy-Efficient Economy.

[25] Cebon, P.B., *'Twixt Cup and Lip: Organizational Behavior, Technical Prediction, and Conservation Practice.* Energy Policy, 1992. **20**(9): p. 802-814.

[26] DeCanio, S.J., *Barriers Within Firms to Energy-Efficient Investments.* Energy Policy, 1993. **21**(9): p. 906-914.

[27] DeCanio, S.J. and W.E. Watkins, *Investment In Energy Efficiency: Do the Characteristics of Firms Matter?* The Review of Economics and Statistics, 1998.

[28] Lutzenhiser, L. *Why Isn't the Housing Stock More Efficient?: Organizational Networks and Technology Transfer*. in *ACEEE 1994 Summer Study on Energy Efficiency in Buildings*. 1994. Asilomar, CA: American Council for an Energy Efficient Economy.

[29] Cooremans, C. *Strategic fit of energy efficiency (Strategic and cultural dimensions of energy-efficiency investments)*. in *ECEEE Summer Study*. 2007. Colle Sur Loop, France: European Council for an Energy-Efficient Economy.

[30] Lutzenhiser, L., K.B. Janda, R. Kunkle, et al., *Understanding the Response of Commercial and Institutional Organizations to the California Energy Crisis* 2002, California Energy Commission: Sacramento, CA.

[31] Janda, K.B., C. Payne, R. Kunkle, et al. *What Organizations Did (and Didn't) Do: Three Factors that Shaped Conservation Responses to California's 2001 'Crisis'*. in *American Council for an Energy-Efficient Economy 2002 Summer Study*. 2002. Asilomar, CA: ACEEE.

[32] National Project Consultants and Exergy, *Low Energy High Rise Building Research Study*, 2009, Warren Centre for Advanced Engineering: Sydney, Australia.

[33] Cushman, M., W. Venters, T. Cornford, et al., *Understanding Sustainability as Knowledge Practice*, 2002, London School of Economics: London.

[34] Ruikar, K., L. Koskela, and M. Sexton, *Communities of practice in construction case study organisations.* Construction Innovation, 2009. **9**(4): p. 434-448.

[35] Zboralski, K. and H.G. Gemunden, *The Impact of Communities of Practice*, in *Encyclopedia of Communities of Practice in Information Knowledge and Management*, E. Coakes and S. Clarke, Editors. 2006, Idea Group Publishing: Hershey, PA.

[36] Lave, J. and E. Wenger, *Situated Learning: Legitimate Peripheral Participation*1991, Cambridge: Cambridge University Press.

[37] Brown, J. and P. Duguid, *Organizational Learning and Communities of Practice: Toward a unified view of working, learning, and innovation.* Organizational Science, 1991. **2**(1): p. 40-57.

[38] Shove, E. and G. Walker, *Diversity and transition: conceptualising the production of cooled space in everyday life*.

[39] Shinn, C.H. *'Super Cool Biz' Springs Sales Boost*. Wall Street Journal 2011 August 16, 2011 [cited 2012 April 13]; Japan Real Time:[Available from: http://blogs.wsj.com/japanrealtime/2011/08/16/super-cool-biz-springs-sales-boost/.

[40] Pless, S.D. and P.A. Torcellini, *Energy Performance Evaluation of an Educational Facility: The Adam Joseph Lewis Center for Environmental Studies, Oberlin College, Oberlin, Ohio*, 2004, National Renewable Energy Laboratory: Golden, CO.

Integrated Energy Master Plans - Local Initiatives with Global Impact

Peter Garforth
Principal - Garforth International llc

Oliver Baumann
President – Ebert & Baumann Consulting Engineers

Gerd Fleischhammer
Principal - Ingenieurbüro Gerd Fleischhammer

Abstract

Global energy use has increased five-fold since 1960, and could double again in the next twenty years, creating major risks over future pricing, supply security and quality, environmental impacts and energy-related legislation. These risks are also creating valuable opportunities for efficient large-scale developments. Larger energy users such as industrial facilities, university campuses, or entire communities traditionally forecast their energy needs by extrapolating from current use, adjusted for growth expectations and modest efficiency gains. Increasingly they require plans that transform their energy infrastructure in a way that extracts the maximum value from changes in both demand and supply choices with the least overall investment and risk.

Improving energy efficiency reduces the need for generation and distribution capacity, limiting plant and network investments. Reliable, cleaner and renewable energy supplies generated closer to final use is a further factor in the transformation of the energy market, along with restructured relationships with traditional utilities. An effective plan balances these layers for highest supply security, least environmental impact and maximum affordability. It also has sufficient flexibility to adjust to new technologies, major regulation changes or other unforeseen events.

Using examples from cities and campuses in the U.S., this paper describes the process of developing high-quality, implementable Integrated Energy Master Plans. It covers the key aspects of a comprehensive energy plan; from establishing an energy and emission baseline and base case outlook; the development and evaluation of energy efficiency and energy supply scenarios; the economic and investment assessments; along with the public outreach and engagement of stakeholders.

The Approach to Integrated Energy Master Plans

Integrated Energy Master Plans (IEMPs) are a powerful tool used to guide the development of an economic, ecological, flexible and secure energy strategy for large-scale energy users such as campuses, military bases, industrial parks, neighborhood developments, or even entire cities and counties. For the purpose of this paper the general term “Community” will be used to refer to these typical sites.

An IEMP lays out an implementation road map to meet or exceed framing goals set by the Community. An IEMP will typically have a 20 to 40 year time horizon. Given this, the IEMP will also include sufficient flexibility to accommodate different cost and technology scenarios without jeopardizing success. An IEMP is different from many energy assessments in that it looks at the entire Community as a single energy object and encompasses the energy chain from final service to primary fuel. This perspective allows investments and policies to be optimized so that they have the greatest chance of meeting the framing goals at the least cost. This approach also means many more stakeholders will need to be engaged and aligned than would traditionally be the case for single building projects or more traditional energy projects.

Framing Goals

All stakeholders and the Team developing the IEMP must be aligned on the overall goals that will be used to assess potential energy solutions and to make recommendations. These goals should encompass economic, supply quality and environmental factors.

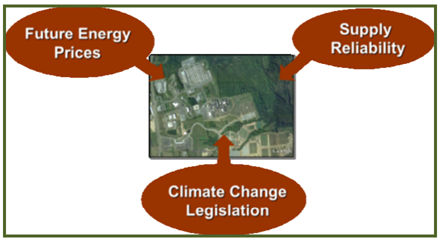


Figure 1: Typical Dimensions of Community Framing Goals

This step decides whether the IEMP will be a breakthrough plan that approaches global best practice or adopts a more incremental approach to energy change. It also ensures that the compromises necessary to meet acceptable results on all three dimensions are clearly understood. As an example, an IEMP developed for the Government Support Center (GSC) in Loudoun County Virginia, an existing 16-building complex that was slated to double in size in the next few years, set the following goals showing a mix of technical, economic and social elements:

- Recommendations achieve at least an 8% Internal Rate of Return (IRR).
- GSC must be a platform for public outreach and awareness of effective energy solutions.
- Primary energy use must be at least 40% less than the Base Case.
- Scope 1 and 2 greenhouse gas emissions must be at least 55% less than the Base Case.
- All buildings will have Energy and Emissions Performance Labeling.
- Energy supply will contribute to existing CHP and Solar PV targets of the County.
- Small district energy (DE) network will be considered.

Every IEMP will have a unique set of balanced goals, and key to its success is aligning all stakeholders early in the process. The goals for the Community Energy Plan[1] for Arlington County, Virginia, an IEMP covering an entire County with a 40 year time horizon to 2050, are illustrative:

- Affordable, reliable energy supplies that are…Flexible to meet changing technologies, legislation and market conditions and that…Meet investor, employer and resident needs and clearly …Meet Arlington's "Cool County" commitment
- Headline Measurement - Reduce Arlington's annual GHG emissions to 3.0 mt CO2e per capita by 2050. If an effective regional energy plan is put in place, achieve 2.2 mt CO2e per capita per year.

In this example the headline measurement was benchmarked against global best practices, coming mostly from the European Union and including the cities of Copenhagen, Stockholm, Mannheim and Freiburg. It was selected on that basis, although it was not seen as immediately achievable based on a purely local assessment. This aggressive goal setting would have been impossible without a rigorous stakeholder engagement process that lasted some months and included academia, major businesses, utilities, county staff and leaders, among many others.

Plan Process

To be a valuable and successful tool for decision making, investment and implementation planning, the IEMP is developed using the following loading order:

- Energy efficiency – "If you don't need it, don't use it!"
- Energy recovery – "It's already there, use it!"

[1] http://freshaireva.us/2011/12/energyplan/

- Renewable energy – “If it makes sense, go carbon free!”
- Energy distribution – “Invest where it makes sense!”

The various efficiency options for both new and existing buildings are systematically reviewed, both in terms of investment and energy impacts, and then referenced from a baseline that can be traced to previous or the current year, as well as a “Base Case” that looks at business-as-usual performance into the future. Various supply and distribution options are also evaluated for the site, including the possibility to team with neighboring facilities to form energy supply clusters. Different combinations are assessed to find a recommended scenario that most closely fulfills the established framing goals.

In most IEMP projects it is not uncommon for there to be a specific alternative energy element that has caught the imagination locally. This may be a particular renewable option such as geothermal; a building standard such as LEED; or a particular technology such as fuel cells or micro-turbines. The IEMP process allows these to be incorporated into selected scenarios, which allows their cost and impact to be objectively assessed as a part of the total community energy system. Sometimes this results in endorsement for the idea, and sometimes in rejection. In either case, the decision is made on a more rational basis, rather than being based on individual or public passion and opinion.

This was exemplified during the development of the City of Holland, Michigan, Community Energy Plan[2]. Prior to starting the IEMP process, the City was committed to add some significant new coal-fired electrical generation; a controversial choice in the community. By incorporating this option into two of the integrated scenarios, it was shown to have less of a negative impact than claimed by some. However, the IEMP analysis also identified two options that were both cheaper and cleaner.

Energy and Emission Baseline

Baseline Data

A sound baseline is the key to the rest of the IEMP. The first step is to collect and analyze the utility data for all the buildings. In some cases, metered energy for every building is available, but this is often not the case on a campus. For larger territories, such as cities or counties, data availability becomes even more complex. In all cases utilities are a valuable resource and all successful IEMPs include existing utilities on their Team.

In addition to utility data, sufficient information on all buildings and facilities must be gathered. This includes building size and character, year of construction and major renovations, type of usage/occupancy, number of occupants and occupancy schedules, type of building systems for heating, cooling, ventilation and lighting, as well as the general conditions of the building and systems. For IEMPs that encompass a smaller number of buildings, it is possible (and advisable) to conduct site surveys in all buildings to collect or confirm the required information. For larger IEMPs it is not possible to conduct individual site surveys for all buildings. In this case, buildings are grouped according to their characteristics. No matter what data is used for the baseline, it is important to document clearly the sources, what is and is not included, as well as all assumptions that have been made to account for missing information and to fill data gaps.

Baseline Calibration

IEMPs use a variety of processes to apply available metered data to the specific uses within individual buildings. This is an interactive process that starts by modeling all buildings or representative buildings that can be considered clones of the larger pool. This sample/clone approach can be done when the pool size is very large, as in the case of a City IEMP, or when the available data is constrained. A building energy use analysis from the GSC example is shown in Figure 2.

---

[2]http://www.cityofholland.com/sites/default/files/fileattachments/final_cep_for_suscom_sept_9_2011_for_website_0.pdf

Model (SI)	Space Cooling	Heat Rejection	Space Heating	Fans	Pumps	Equipment	Interior Lighting	Exterior Lighting	Service Hot Water	Total
Site Energy (Gas & Electricity)										
	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a
Off75_B (Electric Coil)	56.7	-	51.6	70.0	7.0	56.3	15.0	0.6	13.7	271.0
Off75_B (Gas Furnace)	56.7	-	64.5	70.0	7.0	56.3	15.0	0.6	13.7	283.9
Off99_B (Electric Coil)	25.6	-	38.0	53.3	4.1	56.3	15.0	0.6	13.7	206.8
Off99_B (Gas Furnace)	25.6	-	47.5	53.3	4.1	56.3	15.0	0.6	13.7	216.3
Ho75_B	49.8	4.5	147.8	31.2	11.9	114.0	35.2	3.7	89.0	486.8
Ho99_B	42.6	3.7	42.6	66.4	17.3	114.0	42.7	3.7	88.9	421.9
Re75_B	83.1	-	19.9	169.9	-	35.0	84.9	5.1	3.3	401.3
Re99_B	51.1	-	11.6	130.1	-	35.0	84.9	5.1	3.3	321.2
MFH75_B (HeatPump)	44.9	-	26.4	104.8	-	39.4	13.5	0.3	29.5	258.8
MFH75_B (Gas Furnace)	45.1	-	26.7	105.8	-	39.4	13.5	0.3	29.5	260.3
MFH99_B (HeatPump)	22.1	-	13.8	62.7	-	39.4	13.5	0.3	29.5	181.2
MFH99_B (Gas Furnace)	22.5	-	15.0	64.7	-	39.4	13.5	0.3	29.5	184.9
SFHd75_B (HeatPump)	96.6	-	67.1	258.2	-	50.2	13.6	4.0	49.6	539.3
SFHd75_B (Gas Furnace)	97.1	-	40.9	261.1	-	50.2	13.6	4.0	49.6	516.5
SFHa75_B (HeatPump)	78.7	-	39.8	170.5	-	40.6	17.5	1.5	10.1	358.8
SFHa75_B (Gas Furnace)	79.1	-	34.6	172.6	-	40.6	17.5	1.5	10.1	356.1

Figure 2: Typical Sample Building Analysis

This example was analyzed using EnergyPlus[3] version 6. Initial results from tools like EnergyPlus need to be adjusted according to other reference data such as historical building codes, observed condition, CBECS, EnergyStar Portfolio Manager, AGES, VDI3807 and most importantly, the experience of the building experts on the IEMP Team. Adjusting to metered data is required to ensure that alignment between the "known" baseline data and the "estimated" is completed. Thorough documentation is key to handling future challenges and anomalies. A consolidation of end use energy for the agreed baseline year is the last step to enable the integration with the supply baseline.

Existing Utility Supply Structure

From a technical standpoint, this is generally a straightforward step in most IEMPs up to campus level, as long as there is active cooperation of the utilities on the Team. For each utility, the physical layout and specification of networks should be captured, and all efforts should be made to gather the following elements:

- The invoiced amounts and consumption on a monthly basis, avoiding the delay between usage and billing intervals to more accurately match to climate patterns.
- Time interval data typically on 15 to 20 minutes basis for a complete year, to accurately assess instantaneous peaks.
- Contractual terms including economically significant items such as peak penalty conditions.

It is very common in the U.S. and Canada for campuses to have their own heating and cooling networks, or occasionally they are connected to a few city systems that exist. These are rarely well metered so estimates of deliveries and efficiencies become an iterative analysis exercise. An example for annual energy baseline from an IEMP for Drexel University, Philadelphia, Pennsylvania by building category is shown in Figure 3.

Building Category / Function		Electric (MWh/y)	Gas (MWh/y)	Steam (MWh/y)	Total (MWh/y)	Electric (MMBtu/y)	Gas (MMBtu/y)	Steam (MMBtu/y)	Total (MMBtu/y)
Acad/Admin	Classrooms/Offices	24,807	1,699	13,379	39,703	84,667	5,798	45,653	135,506
Residential	Residence Halls/Houses	19,332	6,396	2,319	27,905	65,931	21,829	7,914	95,238
Sci. Research	Labs	9,523	3,545	4,651	17,912	32,501	12,098	15,873	61,133
Athletic	Sport Facilities	5,422	866	2,283	8,532	18,507	2,955	7,792	29,118
Student Life	Theater, Library	3,111	396	1,430	4,914	10,619	1,352	4,879	16,777
Support	Security, Tool sheds	160	592	0	946	545	2,020	0	3,225
Total		**62,356**	**13,493**	**24,061**	**99,910**	**212,820**	**46,052**	**82,120**	**340,993**

Figure 3: Typical Campus Energy Baseline by Building Type

[3] http://apps1.eere.energy.gov/buildings/energyplus/

As an IEMP scales up to City level, energy data is rarely coherently available at building or campus level. For a City IEMP, data is usually collected at substation or pumping station level, with neighborhood use estimated using the baseline analyzed for the buildings. Occasionally, as in the City of Holland, Michigan, detailed property and meter data available in the same GIS system allowed neighborhood mapping of the City energy baseline, which is summarized in Figure 4.

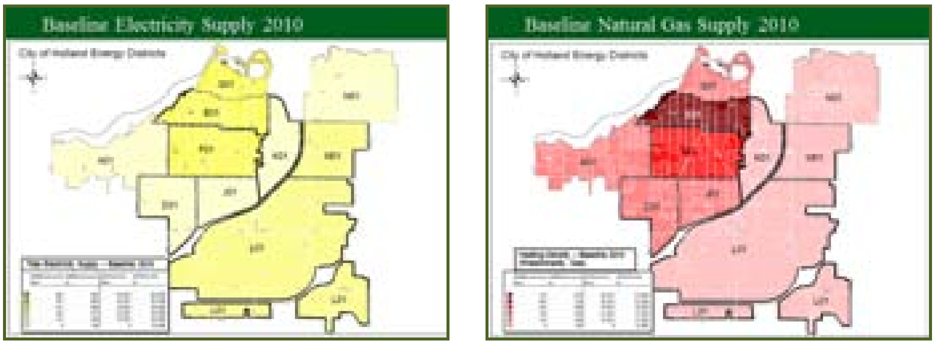


Figure 4: Example of Community Utilities Baseline

The last piece of the energy supply baseline is to fully understand the operating, regulatory and managerial structure of the supplying utilities.

GHG Emissions / Carbon Footprint

The final technical step in establishing the IEMP baseline is to create the energy-related carbon footprint of the campus or the community. There are tools[4] [5] available to do this, with varying degrees of complexity and completeness. For the vast majority of IEMPs, simply multiplying baseline consumption by an appropriate local greenhouse gas index is adequate. The Carbon Footprint Baseline is shown for the City of Holland, Michigan in Figure 5.

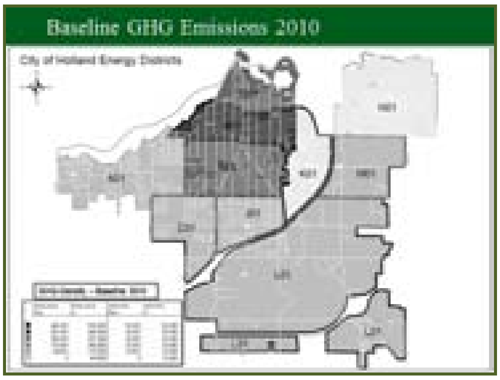


Figure 5: Example of Community Carbon Footprint Baseline

In many IEMP stakeholder groups, there is a wide mix of views over the significance and importance of greenhouse gas reduction. This is one important reason why the IEMP framing goals are always a balance between economic, environment and security. This is also why it is important to recognize the double duty that GHG emissions serve as a reasonably good measure of overall fuel efficiency.

Establishing a Base Case Outlook

Using the baseline as described above as a starting point, a year-on-year Base Case energy demand and consumption, along with the Base Case carbon footprint, for the targeted time frame is developed. The Base Case is used to compare various efficiency and alternative energy supply

---

[4] http://www.campuscarbon.org/

[5] http://carbonn.org/tools/

scenarios used to shape the final IEMP recommendations. These include site and source energy savings, greenhouse gas emissions reductions, investments and economic returns.

It is a never-ending discussion as to what should, or should not, be included in Base Case. In the real future, some things that will improve efficiency, affect costs, reduce emissions or have other benefits will happen through the natural course of things. However, opinions of how fast and to what degree will differ. As with the framing goals, a key stakeholder alignment process is needed to agree these assumptions before lengthy consolidation and analysis proceeds.

As an example, these were the Base Case assumptions specific to the GSC IEMP in Loudoun County, Virginia. They are not untypical, but should not be taken as a general case recommendation:

- All existing building will have the same energy consumption as in the baseline year, meaning that any routine improvements will be balanced by an equivalent deterioration elsewhere.
- All new buildings will be compliant to current local Building Code, ASHRAE 90.1 2004/IECC 2006, meaning that any anticipated code changes are counterbalanced by the non-compliance on the efficiency side. Typical non-compliance in U.S. buildings ranges from 15 to 30%.
- No change in energy supply structure for existing buildings, for GSC meaning stand-alone heating and air-conditioning for each building supplied with gas and electricity.
- All new buildings will have a natural gas boiler in each building, and all electricity will be purchased from the grid.
- The emissions index from electricity from the grid and natural gas from the network will be unchanged.

Based on these assumptions and the expected growth of the GSC, the Base Case through 2035 is shown in Figure 6.

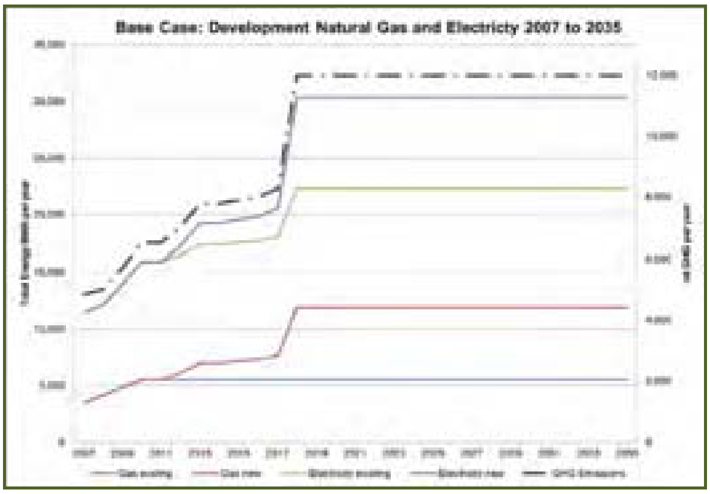


Figure 6: Example Base Case Energy Use for Campus

The City of Holland example Base Case is graphically shown for 2050 in Figure 7, below.

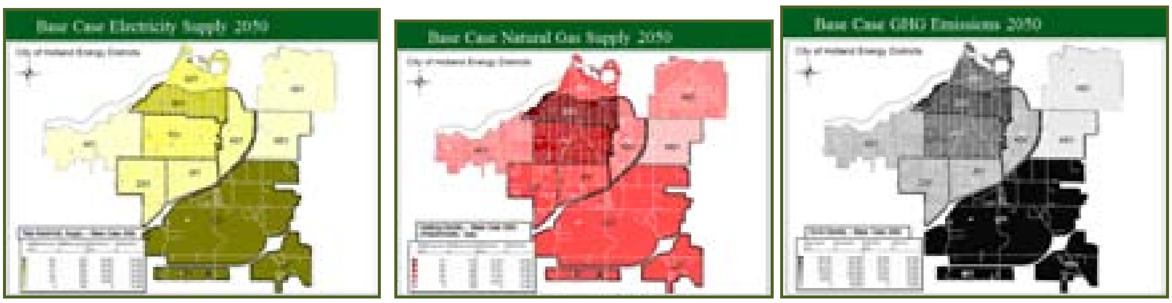


Figure 7: Typical Community Base Case – Energy & Carbon Footprint

Future Energy Demand Scenario

Energy Efficiency Measures – Existing Buildings

Following the IEMP loading order, the first step is to reduce the energy demand of the buildings, typically by both raising the efficiency of the building envelope and reducing internal loads. This includes upgraded insulation along with weather proofing to reduce heat loss in winter and cooling loss in summer. Internal loads such as lighting can be reduced by reducing wattage and using occupancy or daylight sensors. Appliance and IT loads can be addressed through improved procurement. Once envelope improvements have been assessed, heating, ventilation and air conditioning (HVAC) systems are considered for both efficiency upgrades and operational performance. The hot water use is increasingly targeted for reduction through the use of low flow fixtures and possible supply from solar units.

The IEMP by its nature takes a portfolio view of the possible measures in each building and of the buildings themselves. This is done through a combination of experienced judgment and best-fit computer analysis. The overall goal is to find the "sweet spot" where the demand reductions and investments are supportive of the overall site goals. For the ongoing GSC example, Figure 8 summarizes the combination of efficiency measures recommended for the site.

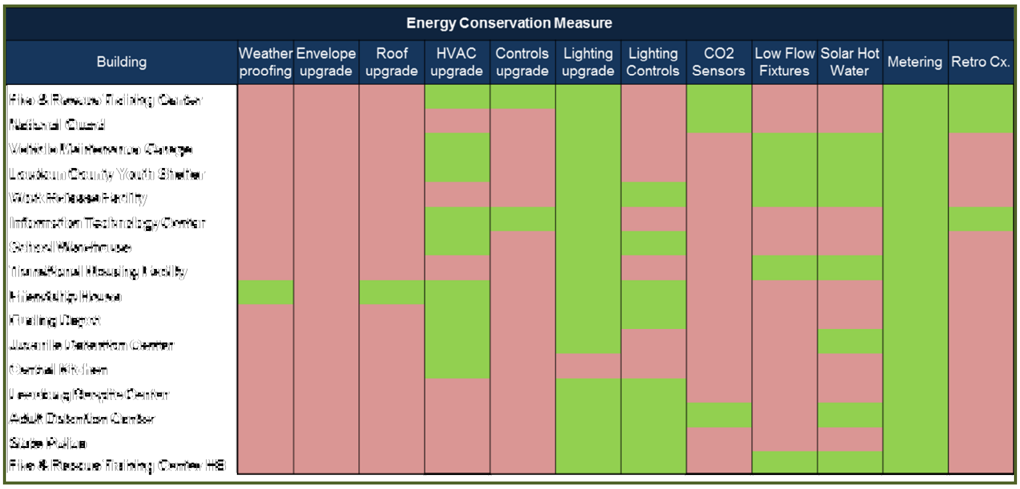


Figure 8: Portfolio of Efficiency Recommendations for Typical Campus IEMP

In this particular example, some buildings are virtually untouched, while others will be substantially retrofitted. For the GSC example, the building efficiency gains are summarized in Figure 9.

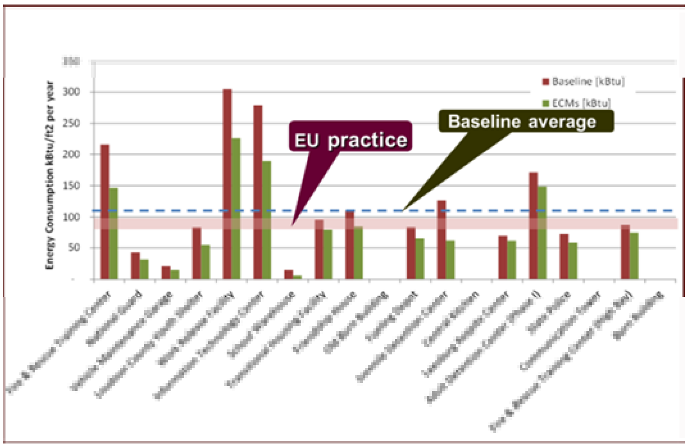


Figure 9: Results of Efficiency Recommendations for Typical Campus IEMP

The total investments are a relatively modest, yet by optimal targeting across the entire site in this example, they create at least a 20% demand reduction.

New Building Efficiency Standard

It is an open secret that in most cases, U.S. and Canadian new buildings have significantly lower energy efficiency requirements than their EU counterparts. Building Code evolution and compliance in much of the region is slow moving, with some specific State and Provincial exceptions. A typical IEMP will set specific performance standards for future buildings, often based on draft future North American Codes, or current EU codes. The cost to meet these standards over and above the Base Case are estimated in the relevant years of the IEMP and treated as part of the investment portfolio.

As examples, the GSC is setting targets to be at least 40% more efficient than Base Case using a draft U.S. standard as the benchmark. The investment to achieve this is less than 2% of the planned construction budget. In Arlington County, the recommendation is to align with the German implementation of the EU EPBD 2012 as a benchmark. Since the requirement is continued with the campus or community scope of the IEMP, the legal status is irrelevant as long as stakeholder agreement is part of the ongoing process.

Ongoing Operating Improvements

Whether for a campus or an entire community, an IEMP will tend to view metering and Building Management Systems (BMS) as elements in a network rather than solely to monitor and control a single building. In nearly every IEMP, a step-wise upgrade of BMS capability within and between existing and new buildings will form part of the assessment. This is the basis of active neighborhood and building management, and is an essential tool for capturing building efficiency. The metering and BMS typically blend into a neighborhood smart micro-grid.

These configurations typically come with extensive reporting and graphics capability, standard in modern BMS and metering systems. This allows the creation of information updates for occupants, visitors and staff. This is a key tool to sensitize staff and users to energy and water use, as well as associated greenhouse gas emissions. Over time, this can build a new culture around energy productivity.

In an IEMP, the combined efficiency effects of retrofitting, new standards and enhanced operations are viewed not as a buffet of possible measures, but as a complete package that will be implemented consistently over many years. If approved and managed in this way, it becomes the basis on which the energy supply scenarios are assessed.

Energy Supply Scenarios

To develop final recommendations, different scenarios combining energy efficiency, distribution and supply are evaluated. Each is assessed for its contribution to the overall energy and carbon footprint, the scale and risk of some key investments, along with how each might affect the economic development of the specific campus or community. Typically supply will include one or two portfolios of efficiency measures for existing and new buildings. As an example, for the City of Holland, Michigan, four supply scenarios were developed, all building on a wide ranging efficiency portfolio. A short description is as follows:

Holland Scenario A

Higher density areas around downtown, the Hope College Campus, Holland Hospital and Holland High School will have new district heating installations. The downtown district heating uses heat recovered from expansion of local electricity generation using a combined-cycle natural gas turbine facility co-located with the existing coal plant. To serve growing electricity demand, a 70 MW combined circle gas turbine (CCGT) configured for district heating will be in operation from 2016.

The prospering industrial area to the south-east (Holland Industrial Park) will be outfitted for district heating services, associated with new combined heat and power (CHP) capacity alongside the existing gas peaking capacity. Industrial services will be based on 30 MW of CHP. Recognizing the importance of low-carbon, low-cost reliable energy services to industrial investors, the City will potentially offer other energy services tailored to a customer’s specific needs. 10MW of “Green Power” from landfill gas are included in the electricity supply portfolio.

Holland Scenario B

This scenario builds on Scenario A, by adding significant renewable energy sources. The CEP analysis used timing assumptions, but these are flexible to allow integration when available and most cost effective, or when required for legislative or regulatory reasons. These include installing 24 MW photovoltaic (PV) generations between 2012 and 2050. This helps meet State Renewable Electricity requirements' and is a significant contributor to the reduction of the summer electric peak.

Other renewable sources in this scenario include a 20 MW biomass generating block replacing part of the existing coal capacity to be in service after 2030. Gas with 10% biogas blend will be used by 2023 for both CHP and CCGT, assuming a wider evolution of the natural gas market. Additionally 37 MW of wind generation will be in place by 2020.

Holland Scenario C

This scenario is identical to Scenario B with the exceptions that a new solid fuel plant instead of CCGT will be used, and there will be no added biomass generating block. The new plant has a capacity of 70 MW from 2016, configured to supply district heating. The fuel mix will be approximately 30% biomass (wood chips) and 70% coal.

Holland Scenario D

This is identical to Scenario C except that the wind and solar photovoltaic capacity will not be added.

Scenario Results

The integration of each of these City of Holland scenarios and the efficiency portfolios has many subtleties well beyond the scope of this paper. Interested readers can find the full report, videos and presentations on line[6].

The evolution of the total fuel use and mix for the City is strategically important and Figure 10 shows how this varies for each of the scenarios by 2050. Its evolution year-on-year is part of the IEMP analysis.

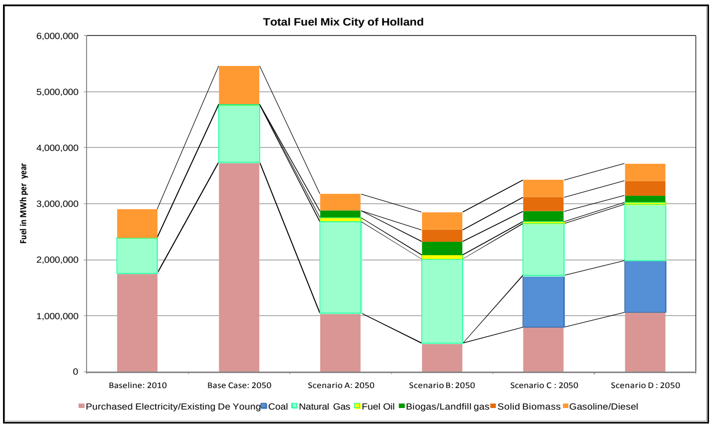


Figure 10: Example of IEMP Analysis – 2050 Fuel Mix for Supply Scenarios - Holland

Energy cost and cost risk is in large part driven by the total fuel needs of the City. This is a complex interrelated blend based on both the overall efficiency of the consumption, distribution and conversion of energy for transportation, heating, domestic hot water, cooling and all other electrical uses. Cost at any given time is also driven by the market price of different fuels and the relative mix.

In the earlier years of the IEMP (CEP) time frame to 2050, the price of natural gas, oil, coal, and biomass will be the main drivers of the overall energy costs of the City. In later years, costs will also be influenced by the operating cost of wind and solar electricity generation which is a significant

[6] http://www.cityofholland.com/sustainability/community-energy-planning-information

component of two of the four scenarios. Flexibility to adjust the fuel mix based on the availability and price of particular fuels is a key factor in deciding on the preferred scenario.

To the surprise of many in the City, by 2050, all scenarios use at least 30% less fuel than the Base Case. Even more surprising was the result that Scenario B used less fuel in 2050 than today, despite major growth in employment and population.

Different fuels cause different levels of greenhouse gas emissions. As part if the IEMP framing goals process described earlier, the stakeholders for the City of Holland had set a 2050 target of 10 metric tons per capita based on German and Scandinavian benchmarking. The per capita emissions to 2050 for all scenarios are shown in the Figure 11.

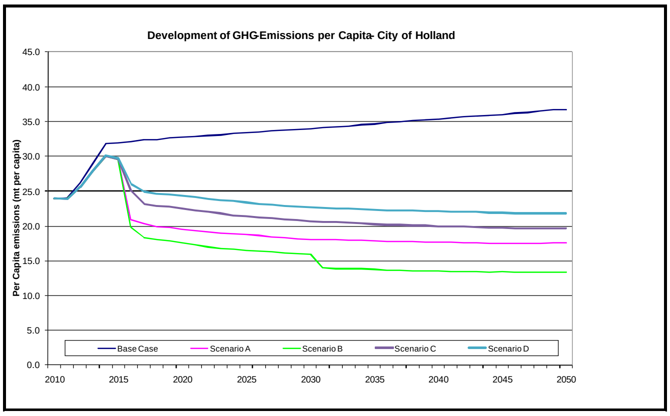


Figure 11: Example of IEMP Analysis – 2010 to 2050 per Capita GHG - Holland

Scenario B results in per capita emissions of 13.4 mt CO_2e compared to the 36.7 mt CO_2e/capita estimate for the "business-as-usual" Base Case. While not meeting the framing goal of 10mt/capita for this specific IEMP (CEP), this scenario puts in place a number of parallel strategies all of which have the potential to be accelerated in future. Specifically, the efficiency recommendations for homes and buildings are relatively modest compared to global best practice and could be intensified.

The stakeholders in this example accepted Scenario B as the basis for their ongoing evaluation of energy practice and policy.

Economic and Investment Assessment

Efficiency Investments

The preceding sections describe examples of the process to build an Integrated Energy Master Plan for a campus or community, and how to select a best fit solution that meets efficiency, flexibility and emissions targets set by the stakeholders. The last step is to ensure the recommendations meet reasonable economic returns and risks.

All of the year-on-year linked analysis spreadsheets used in an IEMP, are structured to not only predict technical outcomes, but to accept each of the estimated investment elements in the appropriate year of implementation. In the case of campus plans such as the Drexel and GSC-Loudoun County examples used, these are pretty specific. In the case of a community IEMP like Arlington County or the City of Holland, these are assessed on a sample basis for a number of neighborhood "Scale Projects", each of which looks like its own campus plan.

By creating a long-term picture of the stream of investment needed to meet specific technical framing goals, the nature of the investment decision changes. In effect, stakeholders are being asked to approve a total portfolio of investments first, which is then broken into its component parts through the implementation phase. This avoids the need to keep "coming back to well" for piecemeal investment decisions. It also avoids the risk that only small, high yield projects such as lighting will be done, and that the game-changing investments around deep efficiency or supply and distribution infrastructure never happen.

Energy Price Assumptions

All too often, efficient and alternative supply projects are evaluated in isolation using either current energy price levels or using very modest future increases. This approach both undervalues future costs and loses the integrated perspective. In all example IEMPs used in this paper, all scenarios were assessed using at least two energy pricing scenarios. The "conservative" price risk used the lower range of the publicly available assumptions from government, utilities, commodities companies and trade associations. The "high risk" price scenario was a mid-range outlook based on more aggressive regulation of greenhouse gas emissions.

As with all critical assumptions that would fundamentally affect the final recommendations and investment assessment, these pricing scenarios were discussed in depth, and agreed by the relevant stakeholders. All of the linked analyses allowed for any specific pricing assumption to change at will to see the effect on technical and economic outcomes for the entire campus over decades.

Integrated Economic Analysis

The last step is to evaluate the financial returns from each of the scenarios. Figure 12 shows the technical results from the IEMP for the GSC-Loudoun County.

Condition		Energy (MWh/year)						Emissions	Savings (%)		
#	Scenario	Gas	Electricity on site	Electricty conversion	DH	Total on site	Total primary	CO_2 (mt)	Energy on site	Energy primary	CO_2
	Including PV Aggressive Scenario New Buildings										
	Baseline 2010	5.610	10.370	21.050	-	15.980	37.030	6.530	48%	45%	46%
	2035 Results										
0	Base Case 2035	12.040	18.420	37.400	-	30.460	67.860	12.020	-	-	-
1	Building effciency	8.020	10.640	21.600	-	18.660	40.260	7.150	39%	41%	41%
2	CHP Island around ADC and New Government SC	11.350	7.740	15.710	-	19.090	34.800	6.450	37%	49%	46%
3	DH from Hydropark	2.040	10.750	21.830	5.520	18.310	36.830	6.290	40%	46%	48%
4	DH from Hydropark with Absorption chilling	2.040	10.180	20.670	7.670	19.890	35.960	6.090	35%	47%	49%

Figure 12: Example of IEMP Scenario Results – Energy & Emissions – GSC Loudoun County

In this example, IEMP Scenarios 4 and 5 met the efficiency and greenhouse gas framing goals. The parallel integrated economic analysis for two pricing scenarios is summarized in Figure 13.

"Conservative" Price Case

#	Scenario	Investment ($)	NPV ($)	IRR (%)
	Without PV	*Aggressive Scenario New Buildings*		
0	Base Case	-	-	-
1	**Building efficiency**	**7,080,000**	**1,880,000**	**9.0%**
2	CHP Island around ADC and New Government SC	9,200,000	110,000	5.4%
3	**DH from Hybrid Energy Park**	**8,940,000**	**640,000**	**6.2%**
4	DH from Hybrid Energy Park with Absorption Chilling	9,410,000	-60,000	5.2%

"High Price Risk" Case

#	Scenario	Investment ($)	NPV ($)	IRR (%)
	Without PV	*Aggressive Scenario New Buildings*		
0	Base Case	-	-	..
1	**Building efficiency**	**7,080,000**	**7,680,000**	**16.6%**
2	CHP Island around ADC and New Government SC	9,200,000	6,440,000	**12.2%**
3	**DH from Hybrid Energy Park**	**8,940,000**	**7,220,000**	**13.2%**
4	DH from Hybrid Energy Park with Absorption Chilling	9,410,000	6,030,000	**11.7%**

Figure 13: Example of IEMP Scenario Results–Investment/Returns – GSC-Loudoun County

In this example, under the conservative price scenario, only the efficiency portfolio for new and existing buildings met the framing goal for investment return. However this fell short of the technical goals. Under high risk pricing, all met the returns, but only 3 and 4 met technical and economic goals.

Through the IEMP process, the final decision for the stakeholders was reduced to a relatively simple choice between Scenarios 3 and 4. The final recommendation was 3 based on local factors.

Public Outreach

The IEMP process is a powerful approach to developing energy plans that can be real game-changers in terms of investments and overall efficiency of community scale developments. However, its success is contingent on the engagement of the "Public" as a stakeholder group from the start of the process. The nature and size of the group will vary significantly depending on scope of the IEMP.

Common to all IEMPs is the need for the stakeholders to be sufficiently senior or influential to represent their constituency. It is also a necessity to include key political, managerial and financial decision makers as well as the local utilities. Most IEMPs involve some critical aspects of public interest, whether for the population at large or local businesses. A well-structured stakeholder group is essential to an IEMP's success to act as an oversight on framing goals, to sort through difficult choices and ultimately support final recommendations.

Equally important is a well-structured stakeholder engagement process. Arlington County was an outstanding example of this. Through most of 2010, the IEMP stakeholders (Task Force) met bi-monthly for three hours, and provided guidance to the IEMP Team in key areas. They also used these sessions and learning opportunities for themselves. All sessions were open to the public and press, again spreading the word throughout the community. In this particular case, most of the Task Force has volunteered to continue in a similar role as the initial IEMP is being broken down into sub-projects for detailed implementation.

Conclusions

In this brief paper, we have attempted to show how the IEMP process can accelerate the renovation and construction of highly efficient buildings, by treating entire communities and campuses as a single energy object. In all the North American examples to date, emissions reductions of at least 50% with investment returns of at least 10% have been typical, with no loss of service quality, and generally with improved supply security and flexibility.

The obvious advantage is the way the IEMP can reduce complex decisions to a relatively simple framework that recognizes the interrelationship between of economic, supply security and environmental goals and find flexible, long-term compromises through a systematic process. Without effective IEMPs the tendency is to focus on small scale efficiencies or individual projects and buildings, and never achieve the scale needed to improve the community, and ultimately, global energy and emissions footprints of our cities.

Without effective stakeholder oversight and engagement, IEMPs will fail to be effectively implemented, however well-structured they may be in terms of data and analysis. Developing an IEMP is a complex blend of politics, team leadership, technical and economic knowledge and risk analysis. Success is achieved by finding balance that works for all.

EVAgreen: Quality assurance and evaluation of sustainable buildings in Germany

Altendorf, Lars; Stefan Plesser, Norbert M. Fisch

***Institute of Building Services and Energy Design,
Braunschweig University of Technology,***

1. Abstract

The research project „EVAgreen: Quality assurance and evaluation of sustainable buildings in Germany“ develops an effective quality control that consistently includes all life cycle phases of a building. The use of an innovative information system aims at practical application on building sites. The need for more powerful tools for quality management is a result of the discrepancy between ambitious goals in the planning and the actual building performance, which often does not meet these expectations.

The “EVAgreen” project is carried out by the Institute of Building Services and Energy Design (IGS) in cooperation with rotermund ingenieure, energydesign braunschweig GmbH and synavision GmbH. It is sponsored by the DBU (German Environment Foundation) and runs from September 2011 to probably the end of 2012.

2. Performance deficits in residential buildings

Political aims for the efficiency of buildings are ambitious in the future: The EU Energy Performance of Buildings Directive EPBD of 2010 targets with its energy policy the implementation of nearly zero energy buildings as standard throughout Europe. The standard is defined by meeting the essential energy need of heating, cooling and warm water by renewable energies, so that the primary energy balance is nearly compensated.
At national level, the EU countries have to implement "climate-neutral building" standard for all new buildings by 2021, for new public buildings already by 2019.
The 2012 amendment to the German Energy Saving Ordinance (EnEV) will introduce a corresponding step-by-step plan.

But how far are the actual building codes reached in practice? Therefore, the difference between a calculated energy level and the actual energy consumption is discussed on an example of residential buildings in the following section.
The figure 1 shows the average heat consumption (energy end use) of residential buildings depending on the year of construction from studies of „Brunata-Metrona-Gruppe“[GRE2010] and „Arbeitsgemeinschaft zeitgemäßes Bauen“ [SEL2010]. Real consumption levels are compared with the calculated energy end use, which results from a parameter study of 5 representative residential buildings. This theoretical analysis is based on input parameters from the different building codes relevant for the different age groups. In the next step, the permitted primary energy demand according to building codes [WSVO], [EnEV] is calculated to get the corresponding final energy demand.

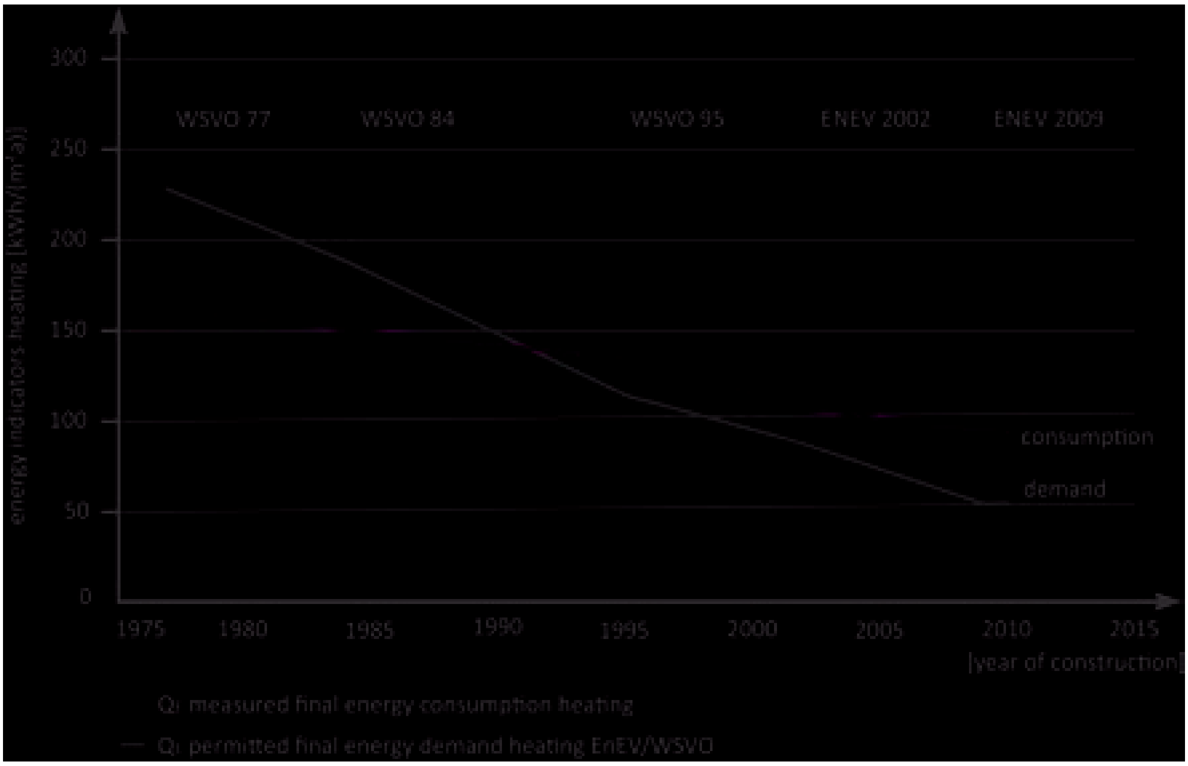


Figure 1 comparison of measured energy demand (IGS) and permittted consumption [GRE2010] [SEL2010] for residential buildings

The figure shows that consumption in older residential buildings (year of construction before 1990) is significantly lower than the calculated demand. The maximum permitted demand of buildings from 1980 is 30 % higher than the consumption.
The main reason for the low consumption in older residential buildings in comparison to the calculated demand lies in the actual use. For example, the mandatory standard is usually based on higher room temperatures and higher air exchange during the heating period than in reality [SCH2010].

In contrast, new residential buildings from year of construction after 1990 have increasingly higher consumptions than the calculation states. Buildings constructed in 2010 consume almost twice as much energy as the permissible demand.
In many cases the high technical quality standards, required by the mandatory building codes, are not reached during the construction phase, what influences the performance of the building. Part of the high consumption can arise from constructional flaws, like thermal bridges and leakages, for example, in vapour barriers with the consequence of moisture damage and reduced effectiveness of thermal insulation.
With increasing improvement of the building envelope, user influence on energy consumption rises in relative terms. Strong user dependent aspects, like hot water consumption, heat losses caused by ventilation and solar gains influenced by the shading of curtains, for example, play a relatively more important role. On the other hand, building operation also gains in importance [WOL2005] [VER2011].

3. Performance deficits in commercial buildings

In case of commercial buildings, planning tools also expect that the building is constructed faultlessly, the building system is used optimally and that the users act "correctly". The energy consumptions of non-residential buildings differ from the calculated demand values in similar way as shown for residential buildings and performance goals are frequently missed in operation [FIS2007].
As in non-residential buildings ventilation and cooling systems are often used to ensure the optimal indoor environment, the focus of the energetic optimization potential is the system operation.

The more complex building systems of commercial buildings indeed offer potential to realize energetic optimized operations, at the same time the risk of defects during installation, operation and maintenance of the facility increases. This has been studied in various research projects: Mansson already showed potential savings of 10% to 30% by optimizing operations in IEA Annex 17 [MAN1997]. The research project EVA by Fisch and Plesser in 2007 revealed more than 50 individual malfunctions in modern office buildings in Germany [FIS2007]. Similar potential and failures showed the research projects ModB [MOD2011] and OASE [BAU2005].

On the other hand, there are deficits in monitoring of energetic targets from legal guidelines. As an example, [EnEV] prescribes since 2007 regular (every ten years) energetic inspections of ventilation systems with a cooling capacity of more than 12 kW, because of particular high saving potentials. A field study on 125 air handling units, carried out by the Institute of Air Handling and Refrigeration, Dresden (ILK) [FRA2011], points out that so far less than 2 % have undergone mandatory inspections. Apparently the control mechanism of this regulation appears to be not working in this current form.

So far, target definitions and classifications of buildings are mostly limited to the planning phase through to completion and therefore stay independent of the real everyday usage. The approach to consider all performance phases and the life cycle is neither consistently nor effectively implemented in requirements profiles, methods and instruments. Especially the technical-economical success during the operational phase is according to German Fee Scales for Architects and Engineers (HOAI) as well as the certification systems DGNB und HQE not at all considered. LEED takes commissioning into account but lacks effective control loops. But exactly this phase is decisive for the actual success of a building concept because the intended sustainability goals like economic efficiency or energy efficiency, user comfort or flexibility are not before now to be redeemed.

Pushing energy efficiency to new limits can only be successful if at the same the quality control of construction and operation is improved. Effective methodologies and tools are urgently needed.

4. Methodology of EVAgreen

To detect deficiencies at an early time and to take fitting measures into action, clear and practicable specifications for the adjustment, operation management or/and operations monitoring of technical building systems need to be defined.
A link between planning and operation is necessary, which guarantees a consistent technical-economical quality assurance in planning, construction and operation of a building and which can be effectively multiplied on a large scale.

4.1 Methodology

With the research project „EVAgreen: Quality assurance and evaluation of sustainable buildings in Germany“ promoted by the DBU (German Environment Foundation) we develop an instrument that contributes to bridging the interfaces in the life cycle of a building. The methodology includes the following working steps:

- Specification
- Evaluation
- Multiplication

The first step is defining clearly specified and easily testable goals with integration into the processes of the project phases. The key element of the project is the continuous and systematic monitoring of these goals by target/actual-comparison in all relevant life cycle phases. A uniform documentation of the valuations enables a multiplication to more buildings.

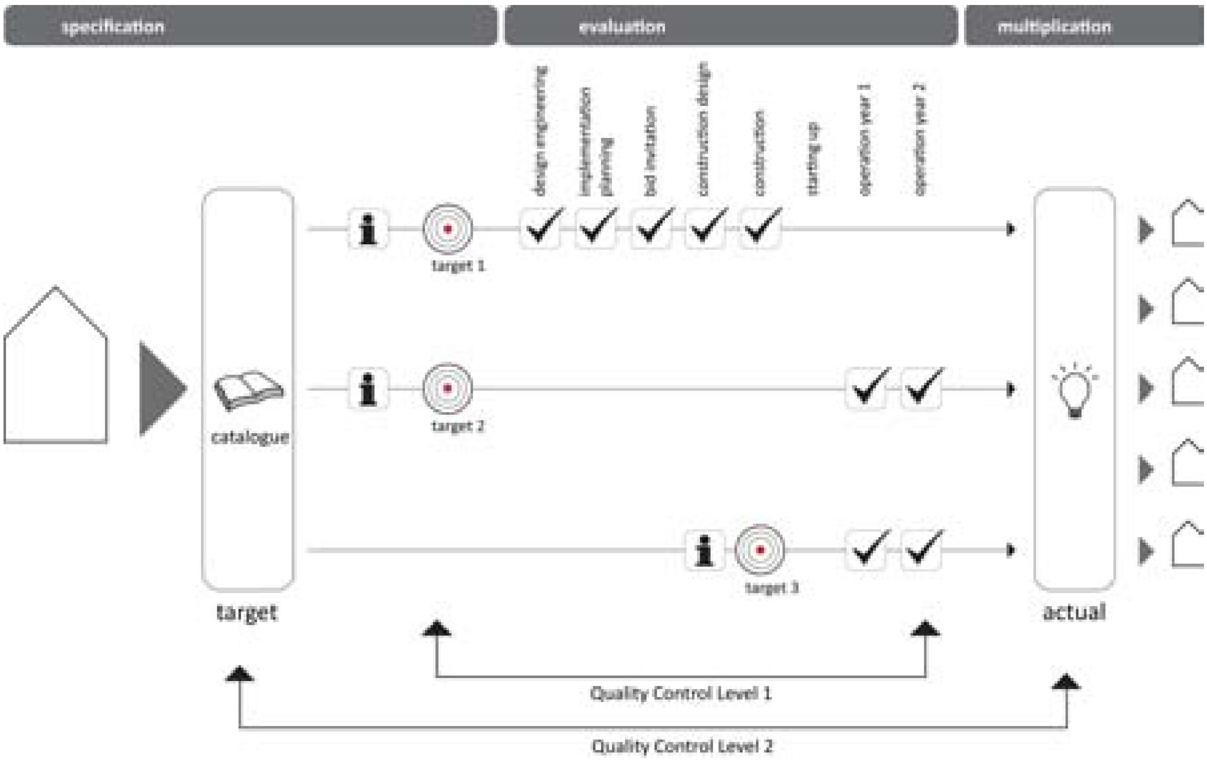


Figure 2 Methodology of the project

4.2 Tools

A web based tool with multi-user access will be used for technical and economic controlling. Service provider, specialist planners and institutional builder can use it to monitor the success from goal definition to operation. A process control via e-mails to the user is intended.
At the beginning of a building analysis – usually at the start of the planning –, a workshop to coordinate building operators, planners and the involved institutes is planned. Target values for the quality assurance of a building are here discussed and selected. Furthermore, a schedule for the entire process control is set. The selection of the target values is made from a catalogue, which is developed within this project. Using a matrix the catalogue describes individual, quantifiable targets and provides information on control. The target values matrix obtains the following categories:

- Building envelope
- Technical installations
- Energy demand (caluculated)
- Energy consumption (measured)
- Comfort
- Economic efficiency

As part of the specifications the user obtains important information on the evaluation as well as guidelines for an easy checking of the goal definition. This includes:

- Technical explanations of the target values
- Statutory limit values
- Information about relevant codes / source and documentations
- Links to further information, Best Practice Examples

For the evaluation the user is instructed via e-mail to prove compliance of the defined target value in the form of test reports at the corresponding project phase. Depending on the target value the time and type of test differ. For example, the heat transfer coefficient of a structural component (see figure 2, target 1) can be verified in the planning phase through EnEV calculation, later through technical specifications or tender documents. During installation in the construction phase a quality certificate can be valid in connection with delivery notes. The verification possibilities end with that. Energy consumption data (see target 3) on the other hand can only be proven by measurements during operation or consumption bills. The following items are included in such an e-mail:

- Scheduling application for process control (start, intermediate date, end)
- Input of reached target value
- Upload of test reports by planner / building operator
- test documentation (photo / text / audio data)

A ticket system will be used as technical solution for this task. Ticket systems allow manual or automated passing on requests and notifications via e-mail and telephone (cell phone, tablet) and structured processing. In the course of this project a further development of the ticket system is planned for the above described functions.

Execution of test tickets on-site, in the form of printed dockets, shall also be possible for the involved people in planning, implementation and operation.

Moreover, the setup of a central database for the analysis of the overall results is intended for this research project. To improve the learning process building operators, architects and technical planners are informed about gained knowledge, like Best Practice experiences, missed project targets and optimization suggestions. That way funding sponsors can be informed about the status and the results of their research project, too.

In practice, the use of the methodology in pilot buildings leads to an important feedback on effectiveness of quality assurance. At the same time the information helps to identify typical quality deficits and causes of suboptimal performance that can be tackled beforehand in future projects.

5. Conclusion

Since the project has not been completed yet, a final conclusion cannot be made at this point. But a survey along project developers and construction provider of certified buildings (DGNB, LEED, Passivhaus) underlines the need to develop an effective quality control that includes all life cycle phases of a building. The process model of quality assurance is currently implemented as a software demonstrator. For validation and optimization, the tool is used for three pilot buildings in service with focus on technical analyses.

References

[GRE2010]
Greller, M.; Schröder, F; T. Bögelein; Hundt, V.
Universelle Energiekennzahlen für Deutschland -Teil 2, Berlin 2010

[SEL2010]
Selk, Dieter. Unsere neuen Häuser verbrauchen mehr als sie sollten, Kiel 2010

[WSVO]
WSVO Verordnung über einen energiesparenden Wärmeschutz bei Gebäuden (Wärmeschutz-verordnung - WärmeschutzV) (1977 /1984 /1995)

[EnEV]
EnEV Energieeinsparverordnung - Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (2007 /2009)

[SCH2010]
Schröder, F., C. Ohlwärter, V. Hundt, B. Mundry: Reale Raumtemperaturen in Mehrfamilienhäusern und Implikationen für die Einschätzung des Heizenergiebedarfs: EnEVaktuell 1/2010

[WOL2005]
Wolff, D.; Jagnow,K.: OPTIMUS- Umweltkommunikation in der mittelständischen Wirtschaft am Beispiel der Optimierung von Heizungssystemen durch Information und Qualifikation zur nachhaltigen Nutzung von Energieeinsparpotenzialen, Wolfenbüttel 2005

[VER2011]
Verbraucherzentrale Energieberatung: Studie - Aktion Brennwertcheck, Verbraucherzentrale Bundesverband e.V. (vzbv) Berlin 2011

[MAN1997]
Mansson, L.-G. et alt: IEA Annex 17: Building Energy Management Systems – Evaluation and Emulation Techniques, Coventry 1997

[FIS2007]
Fisch, M.F.; Plesser, S; Bremer, C.: EVA – Evaluierung von Energiekonzepten für Bürogebäude, Abschlussbericht Braunschweig Hannover, Technische Informationsbibliothek und Universitätsbibliothek, 2007

[MOD2011]
ModBen – Endbericht: Modellbasierte Methoden für die Fehlererkennung und Optimierung im Gebäudebetrieb, Fraunhofer ISE, Freiburg Juli 2011

[BAU2005]
Baumann, O.: OASE - Optimierung der Automationsfunktionen betriebstechnischer Anlagen mit Hilfe der dynamischen Simulation als Energie-Management-System, Abschlussbericht zum Vorhaben OASE, Förderkennzeichen 0327246D, München 2005

[FRA2011]
Franzke, U.; Schiller, H. Untersuchungen zum Energieeinsparpotenzial der Raumlufttechnik in Deutschland, Dresden 2011

Improved indoor air quality by energy efficient air filtration

Thomas Caesar

Abstract

In the context of increasing energy prices and the imperative of reducing the energy consumption and CO_2 emissions, residential and public buildings are getting more and more sealed to avoid uncontrolled heat and energy losses. This also leads to increasingly air tight buildings with significantly reduced natural exchange of inside and outside air. Hence, indoor air quality and its health effects become the focus of attention. Sufficient indoor air quality can be ensured by means of mechanical building ventilation systems, controlling the supply of filtered fresh and recirculation air and the amount of exhaust air for different parts of the building. Counterproductively, air ventilation systems use electrical energy and therefore, finding the best compromise between low energy consumption of buildings in general and ensuring a healthy indoor air quality is the key issue for building planners and ventilation system designers. This includes the optimized use of fresh and recirculation air, low flow resistance in the whole ventilation system, the use of frequency controlled fans and energy efficient particulate and gaseous air filters. The recently published EUROVENT guideline 4/11 [3] defines an energy rating scheme for air filters, which allows users to compare different filters and filtration concept according to an energy efficient operation.

Introduction

To avoid uncontrolled heat and energy losses, residential and non-residential building envelopes are getting increasingly air tight with significantly reduced natural exchange of inside and outside air. This results in an increased accumulation of particulate and gaseous air pollutants, e.g. generated by humans and pets or out-gassing from building materials and furniture. Hence, indoor air quality and its health effects become the focus of attention. Sufficient indoor air quality can be ensured by means of mechanical building ventilation systems, controlling the supply of filtered fresh and recirculation air and the amount of exhaust air for different parts of the building.

Since air ventilation systems use energy and therefore increase the energy consumption of the building as a whole, finding the best compromise between low energy consumption of buildings in general and ensuring a healthy indoor air quality is the key issue for building planners and ventilation system designers. This includes the optimized use of fresh and recirculation air, low flow resistance in the whole ventilation system, the use of frequency controlled fans and energy efficient particulate and gaseous air filters.

Currently, air filters are classified only by their particle collection efficiency e.g. according to the European standard EN 779 [1] or the US standard ASHRAE 52.2 [2]. The initial pressure drop and its evolution during the course of dust loading and hence the energy efficient operation is not yet considered.

With the new Energy-related Products Directive 2009/125/EC (ErP) of the European Commission and the Preparatory Study ENTR Lot 6 “Air Conditioning and Ventilation Systems”, air filters will likely become focus of attention. In parallel, a EUROVENT guideline 4/11 [3] has been recently published, and an ISO standard is currently under preparation, introducing new rating systems to compare air filters in terms of energy efficient operation. Thereby, the use of optimized filtration media and high quality converting technologies are a key for high filtration performance at low flow resistance, and hence, an energy efficient operation.

Indoor air quality

Indoor air quality can be defined by many different parameters. The most important ones are temperature, humidity, fine dust (PM_{10}) concentration and the concentration levels of CO_2 and TVOC. To reduce energy losses, buildings are constructed increasingly air tight with significantly reduced natural exchange of inside and outside air. This results in the fact that today on an average indoor air quality is lower than the outdoor air quality. For example, the natural air exchange of older, less air tight buildings is in the range of 1.3 m³/h per m² of occupied area. Assuming an occupied area per person of 30 m², this calculates to a supply of fresh air by natural ventilation through the building envelope of 26 m³/h per person, which basically meets the requirements of European national standards. The European standard EN 13779 "Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems" [4] defines indoor air quality levels depending on the supply of fresh air per person (see Table 1). According to this definition, 26 m³/h per person relates to a medium indoor air quality (IDA 2). For modern, energy efficient buildings the natural ventilation rate reduces to values of 0.6 to 0.2 m³/h/m², which calculates with the same assumptions as above to a ventilation rate of 4-12 m³/h per person, which is far below the European national requirements and leads to a low air quality (IDA 4) according to EN 13779.

Table 1: Indoor air quality classes to EN 13779 [4]

Air quality class	Indoor air quality	CO_2 concentration in ppm[1]	Supply of fresh air per person in m³/h
IDA 1	High	< 400	> 54
IDA 2	Medium	400 – 600	36 – 54
IDA 3	Moderate	600 – 1.000	22 – 36
IDA4	Low	> 1.000	< 22

[1] above outdoor air level

In general, a trend can be seen that indoor air quality levels are decreasing in Europe, in residential as well as in non-residential buildings, since often no or only insufficient counter measures are taken to compensate the natural ventilation, reduced by sealing the building envelope, e.g. by means of mechanical ventilation. According to a study of the German Federal Environment Agency (Umweltbundesamt), the average indoor air fine dust concentration (PM10) is often higher than the limit value for outdoor air defined in the European Union [5].

Consequently, mechanical ventilation of buildings is getting essential to achieve sufficient indoor air quality levels. Counterproductively, air handling systems for air transportation by a fan and for air conditioning (heating and/or cooling) consume energy, and hence increase the energy consumption of the building as a whole. The actual energy consumption of a fan is related to its energy efficiency, the total pressure drop of the ventilation system and the volume of air supplied. The use of modern, energy efficient fans with variable speed drives with frequency inverter to control the volume flow rate is one of the first measures to ensure an energy efficient operation of air handling units. Approximately 1/3 of the total system pressure drop can be related to air filtration. Depending on the outdoor air quality, air filters with a high particle collection efficiency are required to achieve a sufficient indoor air quality level (see Table 2) and to effectively protect the components of the ventilation system.

Table 2: Air filter recommendations to EN 13779 [4]

Outdoor Air Quality	Indoor Air Quality			
	IDA 1 (High)	IDA 2 (Medium)	IDA 3 (Moderate)	IDA 4 (Low)
ODA 1 (pure air)	F9	F8	F7	F5
ODA 2 (dust)	F7 + F9	F6 + F8	F5 + F7	F5 + F6
ODA 3 (very high conc. of dust and/or gases)	F7 + GF + F9	F7 + GF + F9	F5 + F7	F5 + F6

Air filter classes to EN 779

In general, the pressure drop of air filters increases with particle collection efficiency, and therefore better supply air qualities result in higher energy consumption. Hence, the use of energy efficient air filters can significantly reduce the energy consumption of air handling systems, or with the same amount of energy, result in a better supply air quality due to better filtration efficiencies and thereby contribute to a better indoor air quality.

Background of air filter classification

Typically, to separate fine particles from the air stream in HVAC systems, nonwoven or paper like filter media made of synthetic-organic or mineral (e.g. glass) fibres are used. Mostly, these filter media are converted into 3-dimensional elements, such as pocket filters or pleated cassette filters. The ability of filter media to capture particles from the air stream and hence the particle removal efficiency is based on mechanical effects (inertia forces, interception, gravity and diffusion effects) and the electrostatic interaction between particles and filter fibres.

The efficiency related to the mechanical collection effects strongly depends on the diameter and the density of the fibres. Smaller fibre diameters and denser fibres arrangements typically lead to higher fractional collection efficiencies, but also to a higher air flow resistance and hence higher energy consumption in operation. In contrast to mechanical filters which solely rely on mechanical mechanism to capture particles, electret[1] filters, consisting of fibrous media where the fibres carry electrostatic charge, collect particles by means of a combination of mechanical and electrostatic mechanism. Since the electrostatic forces interact over longer distances compared to mechanical effects, electrostatic charging of fibres increases the efficiency and therefore media require lower fibre matrix density to reach high collection efficiencies. As a result, electret media typically have a lower air flow resistance and lower pressure drop at a given particle collection efficiency compared to pure mechanical filters.

The relation between the pressure drop • p and the fractional collection efficiency $T(x)$ of a filter medium can be expressed by a quality factor (see Equation (1)) often designated as • - or 100•-value [6].

$$\alpha = \frac{-\log(1-T(x))}{\Delta p} \cdot 100\,\mathrm{Pa} \qquad (1)$$

Even though electret filters and filter media have proved their performance in real life operation for many decades, concerns exist on potential electrostatic charge decay. In order to retain the stability of the electrostatic charge and to keep a potential decay to a minimum, materials used as electret filters therefore need to have high electrical resistance. Many of the polymeric materials offer such properties. Polypropylene (PP) is the most popular one, others include polybutylene terephthalate (PBT), poly(tetrafluoroethene) (PTFE), and polycarbonate (PC).

Besides the flow resistance of the filter medium, the overall pressure drop of a filter element is also related to its 3-dimensional structure. Depending on the filter design and the quality of converting, the contribution of the 3-dimensional flow field to the overall pressure drop of a filter element can be up to 80% [8]. As the filter accumulates dust in operation, the pressure drop increases until it reaches a defined final pressure drop and the filter has to be replaced. Modern HVAC systems are typically designed with frequency controlled variable speed drives which give a constant air flow rate. Hence, with increasing pressure drop, the energy consumption of the fan increases. The pressure drop evolution as a function of the time of operation strongly depends on the type of filter medium, the filter design and the quality of converting.

There have been and there are still ongoing industry-wide discussions on how to develop a laboratory test standard that reflects the real field performance of air filters. In Europe, EN 779 [1] defines a filter classification scheme based on the average collection efficiency for 0.4 µm particles. The average collection efficiency is calculated from the efficiency values measured during the course of loading the filter with synthetic ASHRAE test dust. In North America, the test standard ASRAE 52.2 [2] is used to test and classify air filters. The classification scheme in this test standard is based on so-called Minimum Efficiency Rating Values (MERV), which are measured for different particle size ranges during the course of dust loading.

[1] Electret is a dielectric material that has a quasi-permanent electric charge or dipole polarisation. An electret generates internal and external electric fields.

In the test regime of both mentioned standards, the pressure drop evolution during the course of dust loading is measured as well, but is not incorporated into the classification scheme. Air filters are purely classified by their ability to capture dust particles with no regard at all to energy efficient operation. In the light of rising energy cost, classification systems are required which allow users to compare and select filters not only based on the particle collection efficiency, but also with regard to the filters' energy consumption and the total life cycle cost.

Both standards mentioned above also try to evaluate the potential charge decay of electret filters by e.g. chemical treatment of filter media samples. The laboratory test methods described in these standards are known to reveal results for the efficiency, which are far below the values recorded in real life operation. Hence, current test standards used in the industry do not pay sufficient credit to the benefits of synthetic filter media, especially in terms of energy efficiency. There is a strong need to develop test methods which describe the performance of electret filters more realistically, in terms of particulate and energy efficient operation.

Energy consumption related to air filters

The energy consumption of an air filter system is given by Equation (2) [7].

$$E = \frac{\dot{V} \cdot \overline{\Delta p} \cdot t}{\eta \cdot 1000} \quad \text{where} \quad \overline{\Delta p} = \frac{1}{t}\int \Delta p(t)\,dt \qquad (2)$$

In this Equation, E is the energy consumption in kWh, $\dot{V}$ is the volume flow rate in m³/s, t is the operation time in hours, and $\overline{\Delta p}$ is the average pressure drop in Pa. The overall efficiency η of the fan (combined electrical and mechanical efficiency of fan and motor) is related to its design. State-of-the-art fans can reach efficiency values of up to 85%, while the average is around 50%. The operation time of a typical HVAC system during one year is assumed to be 6000 h (24 h per day, 5 days per week and 50 weeks per year). Provided that the volume flow rate and the efficiency of the fan are constant, the only variable parameter is the average pressure drop.

During operation, air filters in HVAC systems are continuously loaded with atmospheric dust, which leads to an increase of the pressure drop. The response and development of the filter's pressure drop depends closely on the design of the filter, the concentration and composition of the atmospheric dust, and the environmental and process conditions involved. Depending on the location of the filter in the HVAC system (first stage without pre-filtration or second stage with pre-filtration) and the quality of pre-filtration, filters are typically replaced by new filters after one to two years of operation either when they reach their final pressure drop or due to hygienic aspects.

Energy related design features of air filters

Typically, in HVAC systems pocket filters or pleated cassette filters made of nonwoven or paper like filter media made of synthetic-organic or mineral (e.g. glass) fibres are used. The ability of filter elements to capture and store particles from the air stream depends on the filter media design and the converting quality.

Figure 1: Typical examples of air filters used in HVAC systems

Differences in the media design can have a great impact on the dust storage inside the filter medium. For example, progressively structured filter media made of synthetic-organic fibers, with in air flow direction increasing fibre fineness and density, are capable to store a much higher amount of dust compared to homogeneous designed filter media. This results in a slower increase of the pressure drop during operation and consequently in a lower energy consumption. Electrostatic charging of filter media also can significantly lower the flow resistance at a given particle collection efficiency as already described above. Additionally, a high stiffness of the filter medium results in stable and self-supporting filter pockets in a V-shape, which is the optimal geometry to ensure minimized energy losses. Also for rigid filters, where typically 6 or 8 pleated panels or one deep-pleated pleat pack is glued into a rigid frame, the stiffness of the filter media and the geometry of the pleats strongly influences the energy consumption and the operational behavior [8].

EUROVENT energy rating system

Up-to-now, the operator had almost no possibility to compare different filters and filter types by their energy related operation performance – except of running extensive test series by himself. In 2008, Mayer et al. [9] published an energy efficiency classification system, which was later the basis for the development of the new classification system according to EUROVENT document 4/11 [3]. With this document for the first time in Europe a system is introduced based on a lab test method which allows an easy to use rating of the energy performance of different air filters.

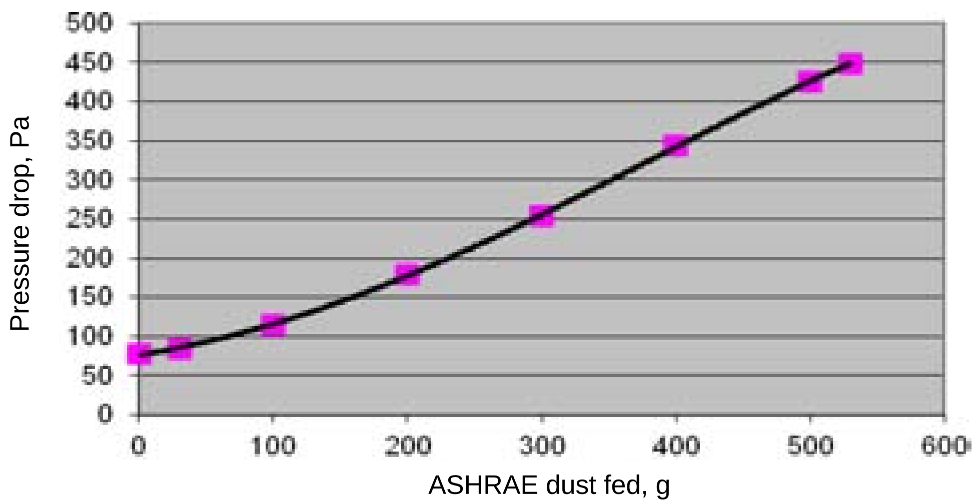


Figure 2: Pressure drop as a function of the dust loading (example given in [3])

Table 3: Class limits for the energy efficiency of a full size filter element (front dimension 592x592 mm) defined per filter class to EN 779 by Eurovent document 4/11 at 3400 m³/h [3]

Filterklasse	G4	M5	M6	F7	F8	F9
MTE	—	—	—	MTE • 35%	MTE • 55%	MTE • 70%
	M_G = 350 g ASHRAE	M_M = 250 g ASHRAE		M_F = 100 g ASHRAE		
A	0 – 600 kWh	0 – 650 kWh	0 – 800 kWh	0 – 1200 kWh	0 – 1600 kWh	0 – 2000 kWh
B	> 600 kWh – 700 kWh	> 650 kWh – 780 kWh	> 800 kWh – 950 kWh	> 1200 kWh – 1450 kWh	> 1600 kWh – 1950 kWh	> 2000 kWh – 2500 kWh
C	> 700 kWh – 800 kWh	> 780 kWh – 910 kWh	> 950 kWh – 1100 kWh	> 1450 kWh – 1700 kWh	> 1950 kWh – 2300 kWh	> 2500 kWh – 3000 kWh
D	> 800 kWh – 900 kWh	> 910 kWh – 1040 kWh	> 1100 kWh – 1250 kWh	> 1700 kWh – 1950 kWh	> 2300 kWh – 2650 kWh	> 3000 kWh – 3500 kWh
E	> 900 kWh – 1000 kWh	> 1040 kWh – 1170 kWh	> 1250 kWh – 1400 kWh	> 1950 kWh – 2200 kWh	> 2650 kWh – 3000 kWh	> 3500 kWh – 4000 kWh
F	> 1000 kWh – 1100 kWh	> 1170 kWh – 1300 kWh	> 1400 kWh – 1550 kWh	> 2200 kWh – 2450 kWh	> 3000 kWh – 3350 kWh	> 4000 kWh – 4500 kWh
G	> 1100 kWh	> 1300 kWh	> 1550 kWh	> 2450 kWh	> 3350 kWh	> 4500 kWh

The used lab test procedure is primarily based on the test method described in EN 779, whereby the filter is loaded at a given air flow rate of 3400 m³/h (0.944 m³/s) with synthetic ASHRAE test dust. The pressure drop curve measured during the course of dust loading (see Figure 2) is used to determine the average pressure drop (see Eq. (2)), related to one year of operation. Depending on the filter class, different amounts of dust are used for this evaluation. This considers the fact that typically filters of group F are used in the second filter stage where they are exhibited to a lower amount of dust compared to group G or M filters, which are typically used in the first filter stage.

With the average pressure drop resulting from the loading curve to EN 779, the annual energy consumption related to the air filter can be calculated using Eq. (2). In EUROVENT document 4/11 as a convention the yearly operating hours are set to 6000 h and the efficiency of the fan to 50%. With the calculated yearly energy consumption, filters are classified into energy efficiency classes according to Table 3.

Currently, the ISO Technical Committee ISO/TC 142 is developing an international standard ISO/PWI 12249-2 for the evaluation and classification of the energy performance o fair filters, where likely the EUROVENT document 4/11 will also be the basis.

Conclusion

In the context of increasing energy prices and the imperative of reducing the energy consumption and CO_2 emissions, residential and public buildings are becoming increasingly air tight, with significantly reduced natural exchange of inside and outside air. It can be shown that modern, insulated buildings without mechanical ventilation systems reach a poor indoor air quality according to the definitions given in the European standard EN 13779. Hence, indoor air quality and its health effects become the focus of attention. Sufficient indoor air quality can be ensured by means of mechanical building ventilation systems, controlling the supply of filtered fresh and recirculation air and the amount of exhaust air for different parts of the building. Counterproductively, air ventilation systems use electrical energy and therefore, finding the best compromise between low energy consumption of buildings in general and ensuring a healthy indoor air quality is the key issue for building planners and ventilation system designers. This includes the optimized use of fresh and recirculation air, low flow resistance in the whole ventilation system, the use of frequency controlled fans and energy efficient particulate and gaseous air filters.

The energy efficiency of air filters depends on many design parameters, and thus largely varies for different filters available on the market. The recently published EUROVENT guideline 4/11 [3] defines an energy rating scheme, which allows users to compare different filters and filtration concept according to an energy efficient operation. This will also be likely the basis for future legal requirements to air filters in the context of the Directive 2009/125/EC (ErP) of the European Commission (Eco Design Directive).

References

[1] EN779: Particulate air filters for general ventilation – Determination of the filtration performance. Beuth, Berlin 2003.

[2] ANSI/ASHRAE Standard 52.2-2007: Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta (2007)

[3] EUROVENT 4/11: Energy efficiency classification of air filters for general ventilation. Association of the European refrigeration, air conditioning, air handling, heating and ventilation industry (EUROVENT), Paris 2011.

[4] EN 13779: Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems. Beuth, Berlin 2007

[5] Bundesumweltamt (German Federal Environment Agency). Gesundheitliche Bedeutung von Feinstaub in der Innenraumluft. Bundesgesundheitsbl – Gesundheitsforsch – Gesundheitsschutz 2008 51:1370–1378, DOI 10.1007/s00103-008-0708-1, Springer Medizin Verlag 2008

[6] Chen, Chun-Wan; Huang, S.; Chiang, C.; et al. Filter Quality of Pleated Filter Cartridges. Ann. Occup. Hyg., Vol. 52, No.3, pp.207–212, 2008.

[7] Goodfellow, H.; Tähti, E.: Industrial Ventilation. Academic Press, 2001.

[8] Caesar, T.; Schroth, T. The influence of pleat geometry on the pressure drop in deep-pleated cassette filters. Filtration + Separation, 39(9): p. 49-54, November 2002.

[9] Mayer, M.; Caesar, T.; Klaus, J.: Energy efficiency classification of air filters. Proc. 10th World Filt. Cong., Vol. 3, p. 313 – 317, Leipzig, Germany, April, 14 – 18, 2008.

Evaluation and optimization of geothermal heat exchanger in energy efficient office buildings

Dipl.-Ing. Franziska Bockelmann, Univ. Prof. Dr. Ing. M. Norbert Fisch

Technical University of Braunschweig, IGS – Institute of Building Services and Energy Design

Abstract

As part of the research project WKSP - heat and cold storage in the foundation area of office buildings (BMWi, FKZ 0327364A), the IGS - Institute for Building Services and Energy Design at the University of Braunschweig (Germany), Univ.-Prof. Dr. Ing. M. N. Fisch - examined the energy efficiency in modern office buildings. The aim of the project was to gain accurate knowledge on the performance of buildings in terms of energy consumption, user comfort and commissioning.

In the first step, in the majority of the researched buildings system errors were analyzed. After these errors have been eliminated, the systems could be operated in respect to their specification. As a following step, optimization measures have been carried out with regard to an efficient operation of the geothermal storage in heating and cooling mode. The paper gives an overview on two most representative buildings analyzed in the project.

With an appropriate design and correct operation of systems based on the geothermal energy storage, the potentials for energy cost savings and CO_2 reductions are considerably significant compared to conventional heating and cooling systems. Moreover, rising energy prices in the future will increase the economic return of investment of using geothermal heat exchanger.

1. Introduction

The reduction of energy consumption in buildings and the sustainable – e.g. CO_2-neutral - coverage of energy demand are the priorities in research and development. An increasing demand for integration of renewable energy and energy-efficient solutions in modern office buildings leads to stronger integration of the soil as seasonal energy storage for heating and cooling purposes.

The aim of the research project WKSP - heat and cold storage in the foundation area of office buildings - funded by the Federal Ministry of Economics and Technology, was an analysis and evaluation of buildings with geothermal heat exchanger. The outcome is a review of knowledge of the actual performance of buildings in terms of energy consumption, user comfort and commissioning.

2. Underground thermal energy storage systems and principle of seasonal thermal energy storage

Drilling a borehole heat exchanger system in the immediate surrounding area of the building or directly below it is one of the ways to use heat and cold storage capacity of the ground. Borehole heat exchanger consists of a single or a network of boreholes. The achievable depth of boreholes is practically unlimited, but a length between 50 m and 150 m has proven to be economically feasible (Figure 1, left).

Taking advantage of synergy effects from pile foundations or foundation boards, including workload and cost reduction, the use of the thermal potential of the ground for heating and cooling should be taken into account in the design-/ construction-phase of the building. Typically, foundation piles or foundation slabs are turned into heat exchanger so-called "energy piles" or "foundation / floor absorbers" for storing thermal energy in the ground. In these cases, the static calculation limits the heat transfer surface.

In the energy piles the probes are part of the foundation piles of the building. The production of energy piles differs only in the implementation of the necessary piping system into the usual production (Figure 1, right).

For all these systems, the heat transfer medium normally consists of a brine (water-antifreeze mixture e.g. glycol).

Figure 1 Coil with borehole heat exchanger pipes (left) and energy pile / foundation pile (right)

[source: IGS and TU Darmstadt]

Using the ground for heating and cooling purposes in buildings, the heat will be injected and extracted into/ out of the ground in a seasonal change.

An advantage of using the ground for heating and cooling buildings is the relatively constant temperature level of the ground over the year. Thus, the soil, for example, can be used for the efficient free cooling mode, without the use of chillers, even at high outside temperatures in the summer.

A requirement for long-term functionality of the system is an active cooling of the soil during the winter and heating the soil in the summer.

During the winter the heat is extracted from the ground and is heated with a heat pump to the required temperature to heat the building. In the summer, the heat transfer fluid is heated in the building and will be cooled down in the ground.

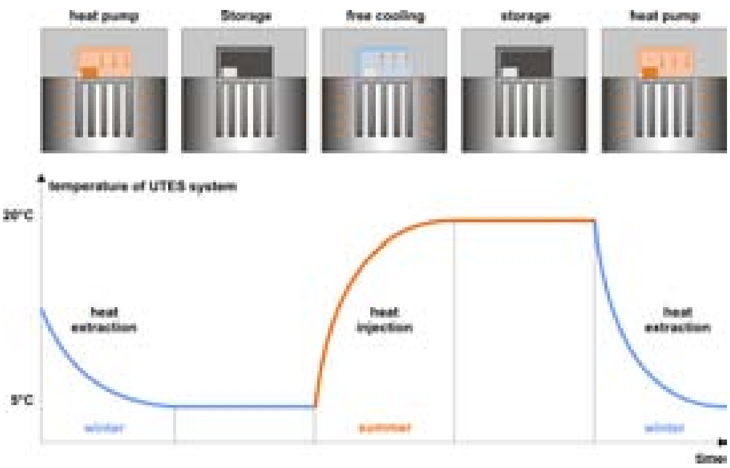


Figure 2 Model of seasonal thermal energy storage in the ground

3. Building example

VGH-Versicherung, Regionaldirektion Lüneburg

The elongated four and a half storey building with a rounded cube on the southeast side contains a gross floor area of about 4.550 m² (Figure 3).

Figure 3 VGH-Lüneburg – view from west- (left) and from south side (right) [source: IGS]

The entrance and the foyer are located in the front area. The staircases situated in the atrium, divide the entire building into two areas. Training rooms are situated on the south-western façade of the ground floor; whereas on the north-eastern side the cafeteria is placed (Figure 4). The two upper floors and the south-western side of the third floor are allotted for offices. The technical control room, stockrooms as well as an underground parking level are located in the basement.

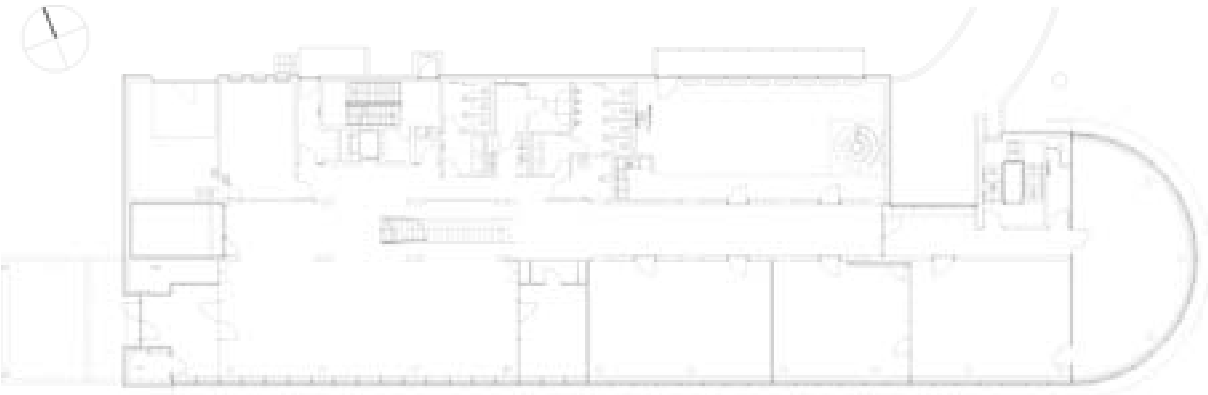


Figure 4 Floor plan ground floor VGH Lüneburg [source: Architekten LMS, Hannover]

Table 1 Overview of the building data VGH Lüneburg

VGH Regionaldirektion, Lüneburg (VGH)						
floor area		**design loads**			**building data**	
ground floor area	4.548 m²	total heat load	350 kW	88,5 W/m^2_{NFA}	year of construction	2002
net floor area	3.957 m²	total cooling load	120 kW	30,3 W/m^2_{NFA}		
		annual heating demand	127 MWh/a	32,2 kWh/m^2_{NFA}	geothermal system	energy piles

Energy concept

The key aspects of the energy concept are efficient ventilation and daylight usage as well as sufficient shading system. Moreover 100 foundation piles, with a length of 17 to 22 meters, are thermally activated for heating and cooling purposes in the building.

In the wintertime a ground coupled heat pump extracts heat from the ground and supplies it into the building. During the day it is used to preheat the incoming air to the entrance hall and the training rooms; whereas in the night time it supplies heat to the thermally activated building systems (TABS) (approximately 1.500 m²) in the offices and training rooms.

The geothermal energy covers the base load of the building. In the case of an increased heat demand during the day, the additional heat from district heating is supplied to conventional radiators in the offices and floor heating in the entrance area. Moreover the district heating can be used for preheating the air supplied to the ventilation systems (Figure 5, left).

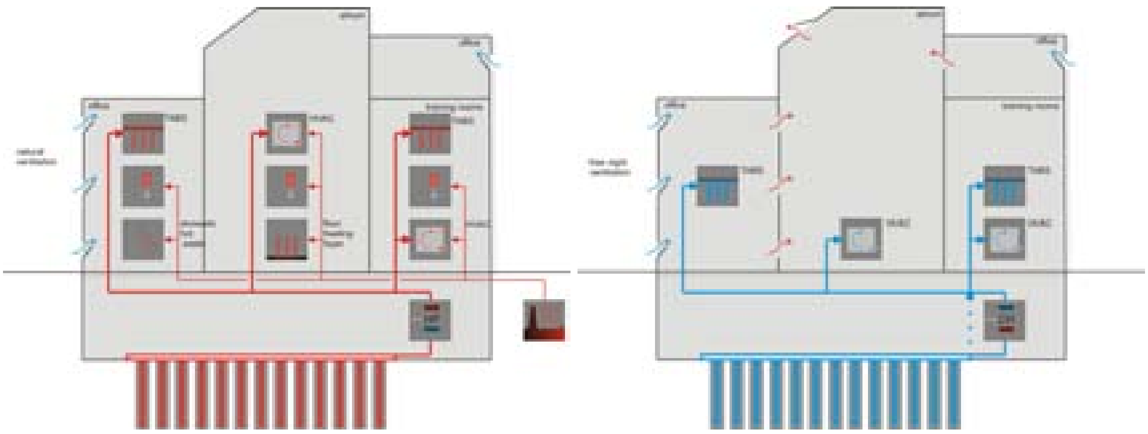


Figure 5 Energy concept VGH-Lüneburg, heating mode (left) and cooling mode (right)

In the summertime, two cooling modes are possible. As long as the temperature of the ground is sufficient, the free cooling mode has priority. When the temperature in the ground rises notably, the reversible heat pump is used as a chiller.

Analogous to the wintertime, the soil is used to pre-cool the air supplied to the ventilation system during the day and to cool down the thermally activated systems in the office and training rooms during the night. The heat is being removed from the building and stored in the soil for the upcoming heating period. In addition the building is being cooled by the natural night ventilation. Through thermal rise the warm air from offices is let outside through exhaust air flaps in the atrium, simultaneously cool air flows through the tilt windows into the building (Figure 5, right).

Optimization and system performance

In the first years of operation, the entire system of VGH did not work reliably, so that a continuous monitoring and controlled heat extraction and injection into the earth were not recorded. The heat extraction from the soil was minimal in the past and also the heat injection, the operation of the free cooling mode or of the chiller did not seem to work ideal. The free cooling mode has been possible so far only in the TABS mode and was in the past probably not really used (Figure 6).

Causes of the problems were execution errors and poorly coordinated control strategies for the various system modules. Various errors were identified such as control failures, inappropriate hydraulic distribution (installation of a leaking motor valve between supply and return) and a faulty supply temperature control throughout the system.

Moreover, a lack of coordination and implementation of building use, building control and energy control center has reduced or blocked the functionality of the system significantly, so that in the first years the required thermal performance of the building was covered by district heating.

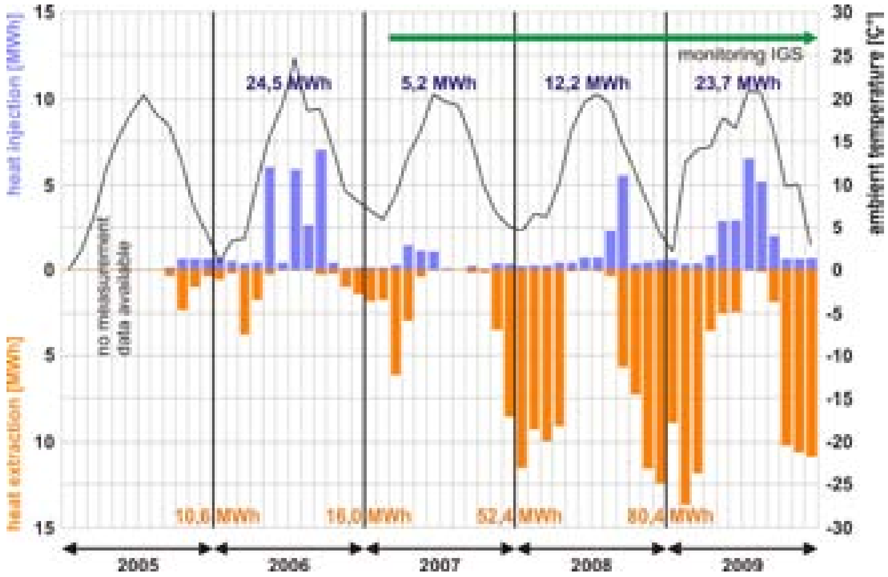


Figure 6 Monthly heating extraction and injection as well as ambient temperature, 2005 – 2009

Even in the ventilation system deficiencies were located. Based on building measurement system (BMS) data, it was found that during the night and on weekends the circulation pumps of the heating coils of the HVAC system connected to the geothermal power station were running and also supplied with district heating. It is intended that the ventilation system should be shut down during this time. After a check and changes in the operating hours of ventilation system, correct operation was achieved.

Significant control oriented changes are:

- Reduction and adaption of the supply temperatures to the TABS and HVAC system.
- Expansions of the set supply temperature of the HVAC system in the cooling operation to enable the use of free cooling at the beginning of the cooling period.
- Considering a neutral ambient temperature (dead band) where the energy pile system is deactivated during the transition period.

After successful fault correction and optimization of the control strategies, a steady increase in heat extraction as well as heat injection was recorded. A scheduled heating operation in spring 2007 and a scheduled cooling operation in summer 2009 were realized (Figure 6).

The district heating supply was reduced by the scheduled heating operation in 2008, so that 29% of the heat was covered through the geothermal heat system. Due to the cold winter of 2008/2009, the coverage dropped to 24% in 2009 (Figure 7).

During the monitoring, the fraction of the geothermal heating and -cooling supply as well as the heat injection and extraction were improved. A seasonal performance factor (SPF) of 4.1 was achieved in 2009 (Figure 8). This compares to an efficient heat pump, which is characterized with a SPF> 3.0.

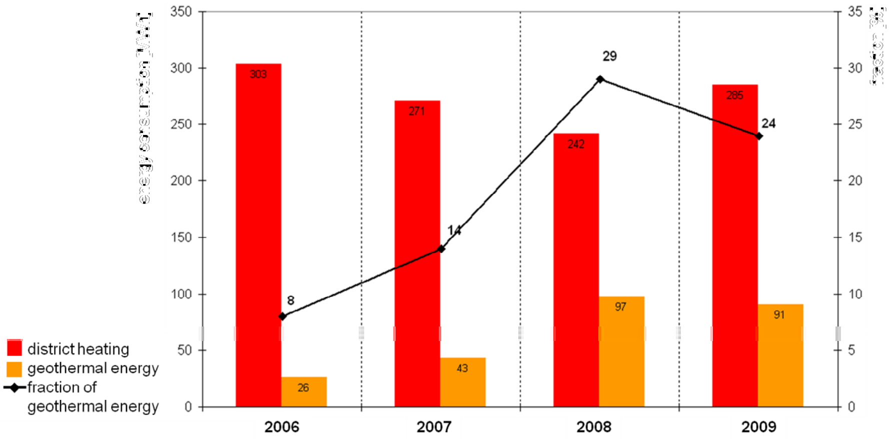


Figure 7 Annual energy consumption for district heating and geothermal heat with fraction of geothermal energy to the total heating consumption, VGH, 2006 - 2009

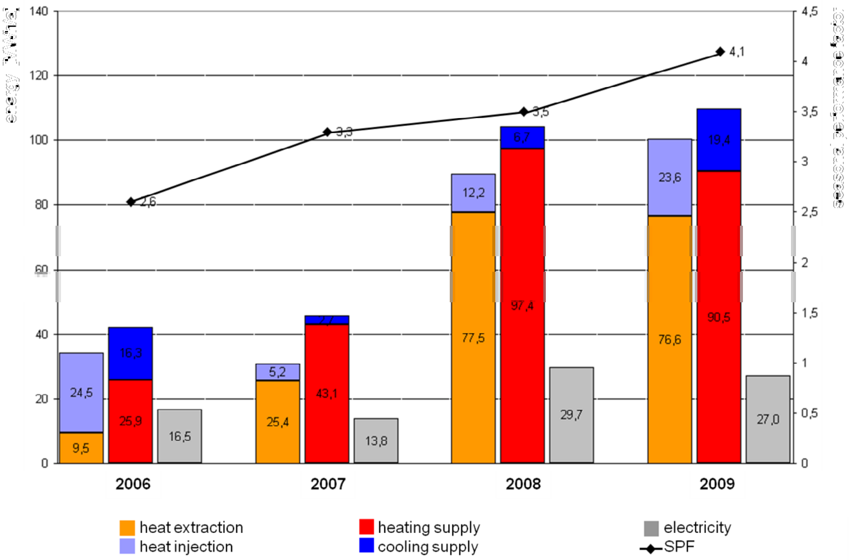


Figure 8 Heat extraction and injection to the ground, geothermal heating and cooling supply as well as electricity consumption and SPF (stacked), 2006 - 2009

Head office GELSENWASSER AG, Gelsenkirchen

The new building of the head office GELSENWASSER AG assumes the proportions of the existing white building and duplicates it to form a glass twin (Figure 9). It consists of seven floors, a penthouse and a basement with technical and computer rooms.

In the office floors, a wide central corridor serves as a communication zone. Individual and group offices are arranged on the west and east side of the corridor. Whereas meeting rooms and two-storey winter gardens are located in the northern area of building. The southern areas are used partly for large offices. A large conference room with a roof garden and central ventilation are placed in the penthouse (Figure 10).

Figure 9 Old building „white house“ and new building „transparent house“ of the head office GELSENWASSER AG – view from the north and south-west side [source: IGS]

Figure 10 Floor plan ground floor, „transparent house“ [source: Anin Jeromin Fitilidis & Partner, Düsseldorf]

Table 2 Overview of the building data GELSENWASSER AG

Gelsenwasser AG, Gelsenkirchen (GEW)						
floor area		**design loads**			**building data**	
ground floor area	7.114 m²	total heat load	270 kW	43,6 W/m^2_{NFA}	year of construction	2004
net floor area	6.189 m²	total cooling load	305 kW	49,3 W/m^2_{NFA}	geothermal system	borehole heat exchanger
		annual heating demand	n/a MWh/a	n/a kWh/m^2_{NFA}		

Energy concept

A borehole heat exchanger system, consisting of 36 double-U-probes with a depth of 150 m, is the basis of the heating and cooling supply of the building. The waste heat of the existing gas-CHP (combined heat and power plant), which was previously only used for heating in winter, can now be used throughout the whole year to heat both old and new building in winter time and for drying and cooling the supply air with a Desiccant cooling system (DCS) in summer time.

Heating and cooling in the building is assured with heating and cooling ceilings and a HVAC system. Each floor is divided into four zones that can be controlled independently, so that it is possible to heat and cool the zones parallel. The heating / cooling ceilings are completely supplied by the borehole heat exchanger system. (Figure 11, left)

The old building was also included in the cooling concept of the new building. So, in addition, the cooling facade system and the ventilation system for cooling the conference area in the old building are supplied with cold. Apart from the DCS to supply air to the office area (ground floor, 1st to 6th floor) and the meeting room on the 7th floor, the new building is heated and cooled monovalent through the ground. In addition to mechanical ventilation, there is the possibility of natural night ventilation and removal of hot air via special apertures in the facade, like gills. (Figure 11, right)

The energy concept of GELSENWASSER AG allows three operation modes:

1. In a combined heating and cooling mode the heat pump uses internal loads from the building as a heat source, supplying heat to other areas.
2. In spring, the cooling potential of the soil will be used in free cooling mode without a chiller.
3. The reversible heat pump is used as a chiller, the waste heat is stored in the ground by the probes.

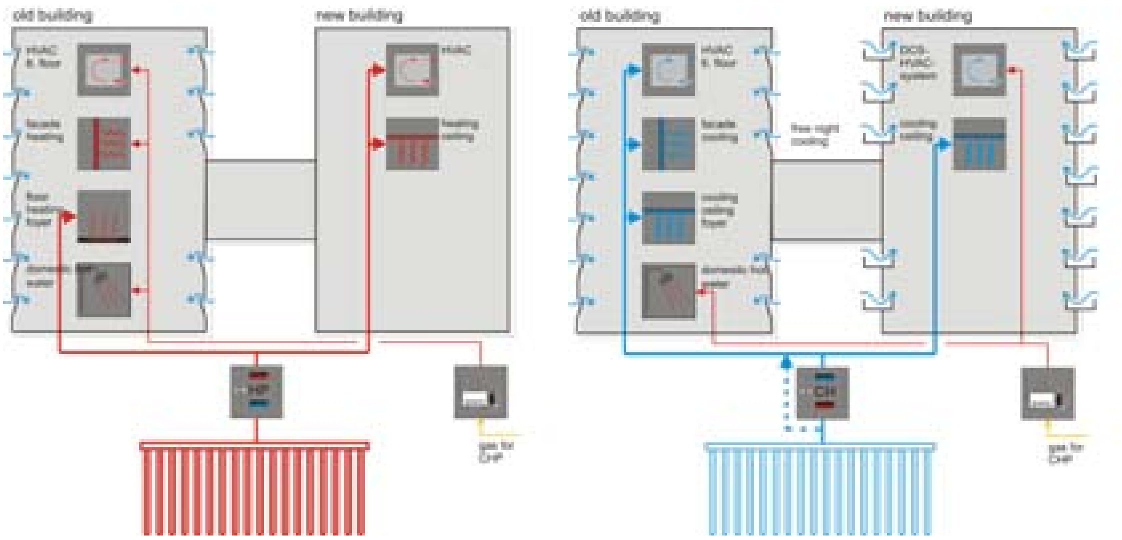


Figure 11 Energy concept Gelsenwasser AG, heating mode (left) and cooling mode (right)

Optimization and system performance

In the first years of operation, the heat required for the building came from the main building itself instead of the ground, so that only a little fraction of heat could be extracted from the ground. The result is an uneven seasonal energy balance of the borehole heat exchanger.

In the summer, also about 85% of the cooling was provided by compression-chiller operation, while the design schedules an approximate cold coverage of 68% through the free cooling mode and only 32% from the chiller operation.

The increased “chiller-only-mode” and the low heat extraction causes:

- an unplanned increase of electricity consumption,
- a rapid increase of soil temperatures,
- the efficient free cooling mode cannot take place. (Figure 12)

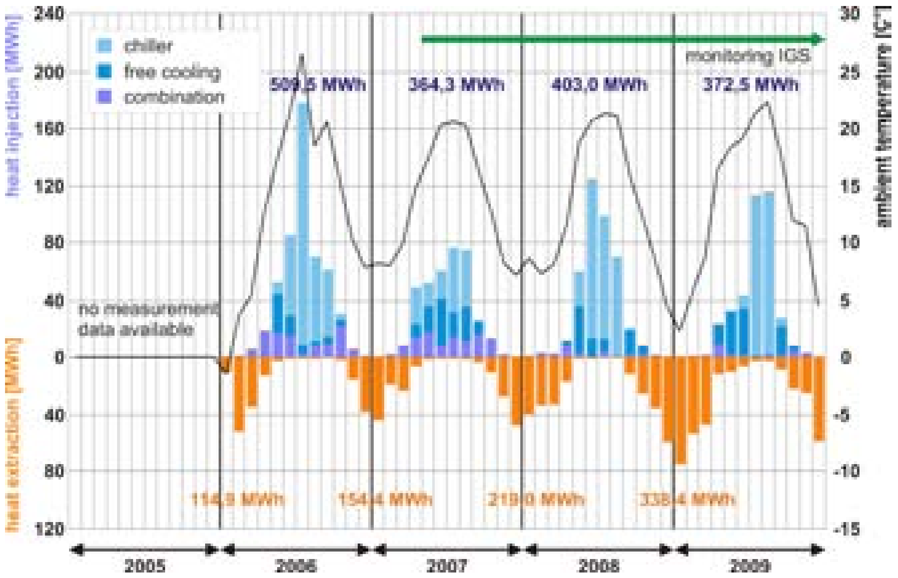


Figure 12 Monthly heating extraction and injection as well as ambient temperature, 2005 - 2009

In order to prevent continuous increasing of the soil temperature and therefore making it impossible to use the free cooling mode, the extraction of heat in proportion to the heat injection has been increased significantly. The aim was to cool down the soil and to keep the ratio between heat injection and extraction balanced to enable stable and efficient free cooling operation.

Implemented optimization measures to reduce the cooling demand are:

- Adjustment of the schedules of the chiller to the actual boundary conditions – activation of the chiller by higher supply temperature
- The night cooling of buildings through the ventilation system is replaced by natural ventilation.
- Adaptation of the ventilation concept: air exchange in the offices as well as strict adherence to the nominal values of room temperatures are not required on weekends, thus limiting the exhaust fan operation and a natural ventilation and cooling over the wall flaps in the night hours.
- Outdoor air fan operation is not useful in the winter months, thus prevent opening of the wall flaps and operation of the exhaust fan at very cold temperatures

The success of the measures is a clear reduction of the heat injection into the soil as well as the operating hours of the chiller compared to the previous year (Figure 12 and **Error! Reference source not found.**). In 2009, the ratio of free cooling to chiller operation increased from 30% to 70%. As a result, the chiller operation was only necessary in the summer time, when the required supply temperature cannot be realized with free cooling mode. Moreover, the heat extraction from the ground in 2009 was almost twice the amount compared to 2007.

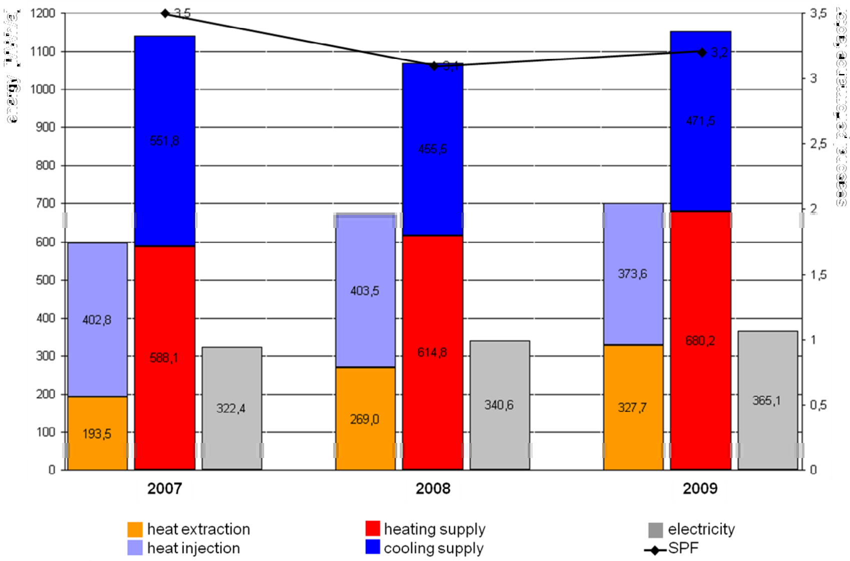


Figure 13 Heat extraction and injection to the ground, geothermal heating and cooling supply as well as electricity consumption and SPF (stacked), 2007 - 2009

4. Energy cost savings and CO_2-reduction

The energy cost savings and CO_2 reductions which can be achieved by thermal usage of the soil compared to a district heating and cooling by conventional compression chiller (assumption: SPF of 2.5) strongly depend on the size, efficiency and usage of the system.

If using energy prices and CO_2 emission factors shown in Table 3, energy cost savings (absolute) fluctuated between 970 and 37.300 € / a (Figure 15) and CO_2 reductions between 1.890 and 74.400 kg / a (Figure 16) were scored in the years 2006 to 2009, depending on the object and content of the heating and cooling supply.

Table 3 Energy prices and CO_2-emission factors for calculation of energy costs and CO_2-emission

	electricity	district heating
Energy costs [€/kWh]	0,12	0,08
CO_2 emission [kg/kWh]	633	219

In relation to a kWh_{therm} the energy price for geothermal energy for the presented buildings results in 3.6 to 5.9 €cents for the heating case and price of 1.3 to 5.2 €cents for the cooling case (depending on free cooling mode or chiller). The energy costs are thus during heating mode and chiller operation at approximately half of the costs of conventional sources and to just 1/10 of the energy costs by using free cooling mode (Figure 14).

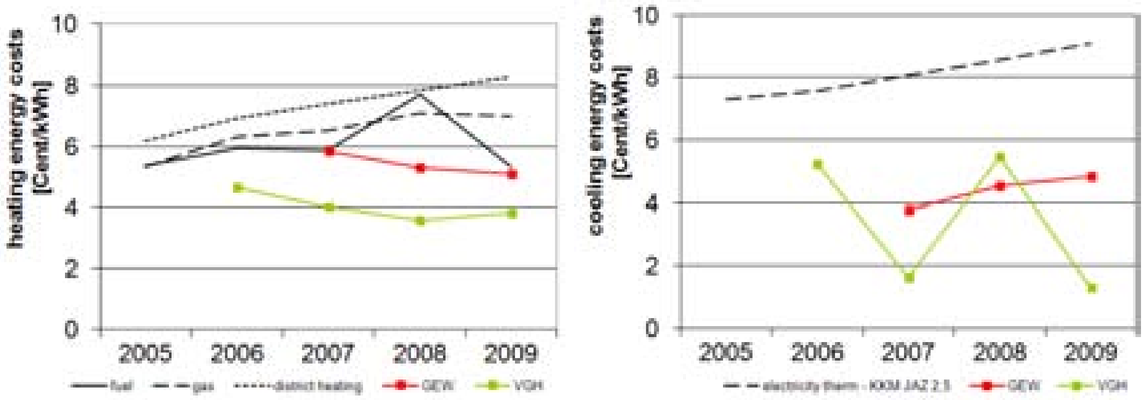
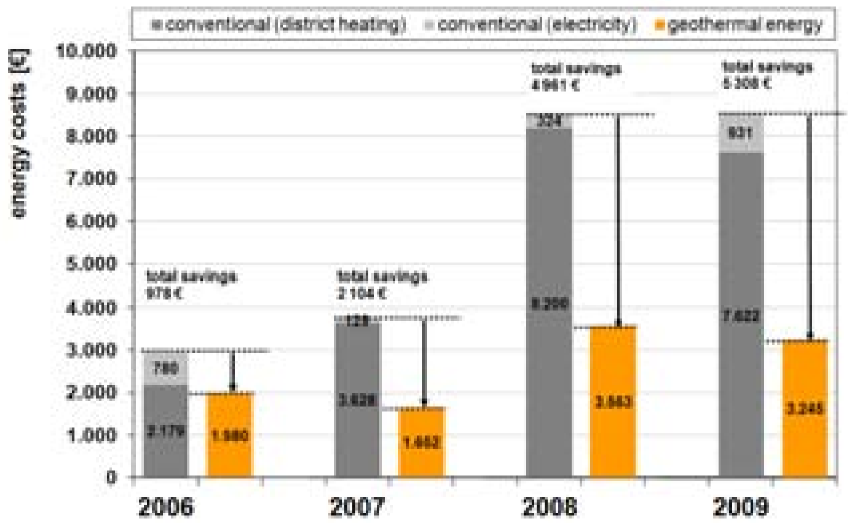
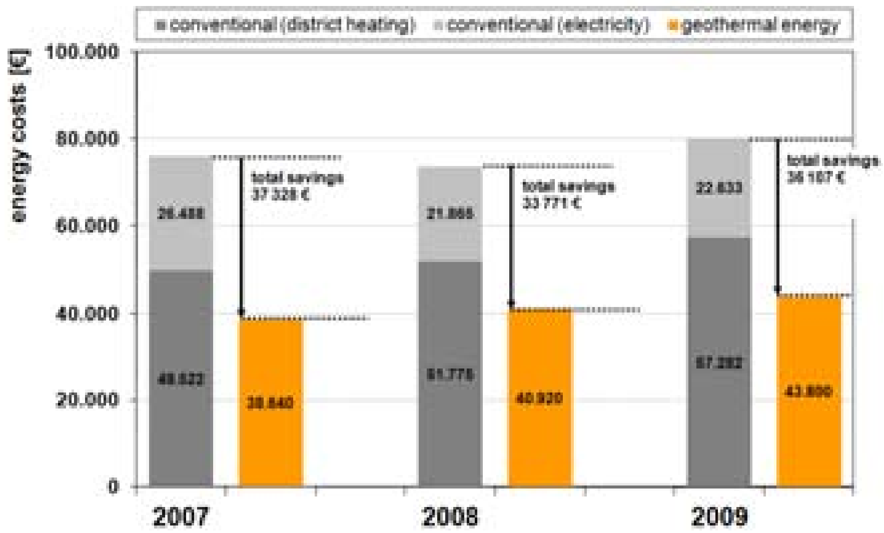


Figure 14 Energy costs for heating and cooling [source: Statistisches Bundesamt]

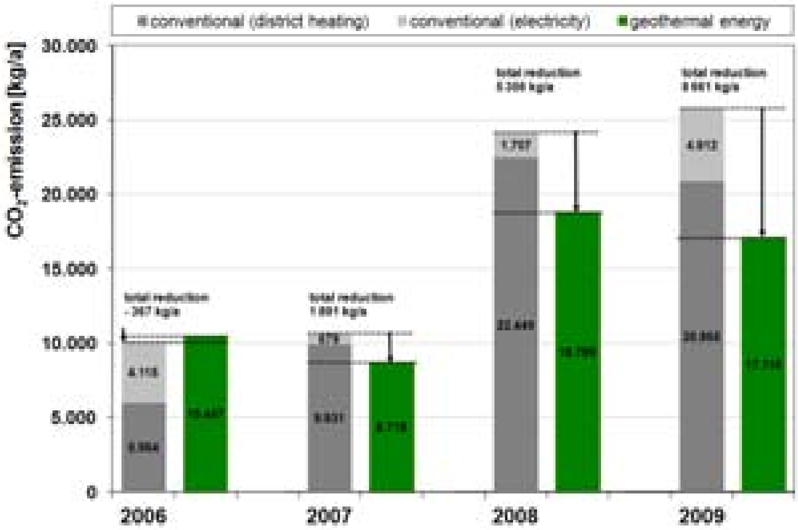


VGH - Lüneburg: fraction of geothermal heating 24% and cooling 100%

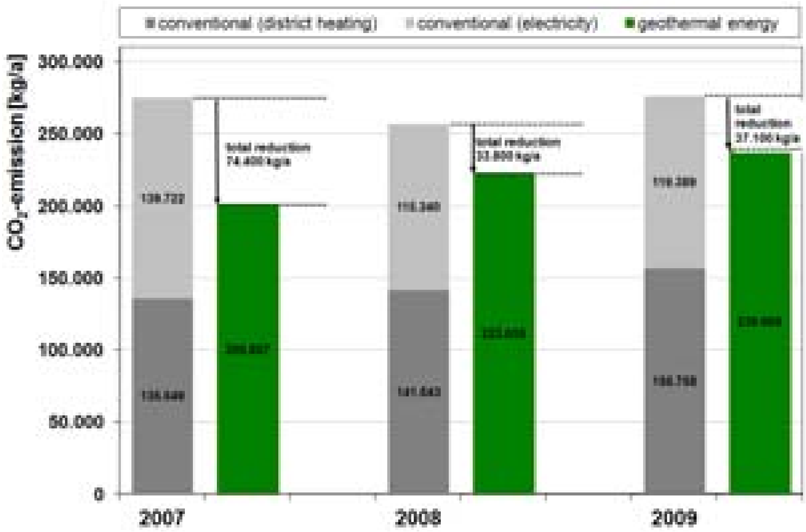


GELSENWASSER AG: fraction of geothermal heating 81% and cooling 100%

Figure 15 Absolute energy cost savings in comparsion with district heating and compression chiller (JAZ = 2.5), 2006 - 2009



VGH Lüneburg: fraction of geothermal heating 24% and cooling 100%



GELSENWASSER AG: fraction of geothermal heating 81% and cooling 100%

Figure 16 Absolute CO_2-emission and reduction in comparsion with district heating and compression chiller (JAZ = 2.5), 2006 - 2009

5. Conclusion

For a successful and sustainable operation of the foundation piles or borehole heat exchanger, high quality standards have to be taken into account in the planning, implementation and operation. In general, it is possible to integrate geothermal energy system components into an overall concept. However, it is recommended to holistically synchronize the control strategies of each system in the building as well as to control and to adjust them during the operation.

With an appropriate design and correct operation of systems based on the geothermal energy storage, the potentials for energy cost savings and CO_2 reductions are significant compared to conventional heating and cooling systems. Moreover, rising energy prices in the future will increase the economic return of investment (reduce the payback time) for using geothermal heat exchanger.

References

[1] Bockelmann, F., Kipry, H., Fisch, M. N.: Forschungsbericht: WKSP – Wärme- und Kältespeicherung im Gründungsbereich energieeffizienter Bürogebäude, BMWi Fkz 032736A, November 2010.

[2] Bockelmann, F., Kipry, H., Fisch, M. N.: Erdwärme für Bürogebäude nutzen, BINE-Fachbuch im BINE Informationsdienst, Frauenhofer IRB Verlag, Stuttgart (2011), ISBN 978-3-8167-8325-1

[3] Kipry, H., Sasse C., Fisch, M. N.: Auf dem Prüfstand X, XIA Intelligente Architektur, Ausgabe 07-09/2007

[4] Bockelmann, F., Kipry, H., Fisch, M. N.: Auf dem Prüfstand XVI, XIA Intelligente Architektur, Ausgabe 10-12/2009

Energy Recovery in Air Handling Units by Using Multifunctional Integrated Circuit Systems

Dr.-Ing. Raffael Ahmed

GEA Air Treatment GmbH

Abstract

The importance of energy recovery in air handling units grows continuously due to revised standards and regulations. The recovered heat coefficient (RHC) is a characteristic for the efficiency of energy recovery systems. To meet the customer's demands, the design of the system requires the evaluation of an optimal RHC. One objective of this paper is to demonstrate that larger RHC values may lead to a decrease of energy efficiency. Life cycle costs (LCC) calculations show that smaller values may be preferable, depending on various criteria such as application, location and energy prices.

In integrated circuit systems, energy is transferred between the air sides by means of a circulating heat transfer medium. For given heat exchanger geometries the medium mass flow rate has to be optimized to provide maximum heat transfer. A basic approach to determine the optimum and difficulties to adapt it to multifunctional integrated systems will be discussed here.

Multifunctional systems are integrated circuit systems with further thermodynamic functions such as feeding-in from external heat sinks and sources. Using the example of integrated heating and cooling, the benefits in comparison to basic systems are demonstrated by means of a LCC analysis.

Introduction

The objective of energy recovery in air handling units is the reduction of primary energy consumption. Integrated circuit systems are used in HVAC applications especially if ambitious requirements have to be met with respect to hygiene and to the separation of air flows. At this, energy will be transferred from an exhaust air coil to a supply air coil by means of a circulating heat transfer medium, cf. Figure 1. The optimal medium mass flow rate will be adjusted by means of a speed controlled pump. The heat exchangers operate in cross counter flow. In general two further coils are necessary to heat or to cool the outlet air of the energy recovery system and thus to provide the requested supply air temperature.

The first section of this paper investigates the question which recovered heat coefficient is optimal with respect to the customers' requirements. In the second part we evaluate the optimal medium mass flow rate in integrated circuit systems. The third section deals with specific energy recovery systems, known as multifunctional systems.

Optimal Recovered Heat Coefficient

The choice of an integrated circuit system that perfectly meets the customers' demands is a challenging task, depending on e.g. application and location. Therefore custom-made solutions have to be found which fulfill conflicting interests, cf. [1;2]. For example small fouling tendency of the fins can be obtained by large fin pitches, but in general this leads to both increased length and price of the coil.

In Figure 1, ϑ' and ϑ'' denote inlet and outlet temperatures, k is the overall heat transfer coefficient and A the heat transfer area. The heat capacity rates of both airsides and of the heat transfer medium are defined as

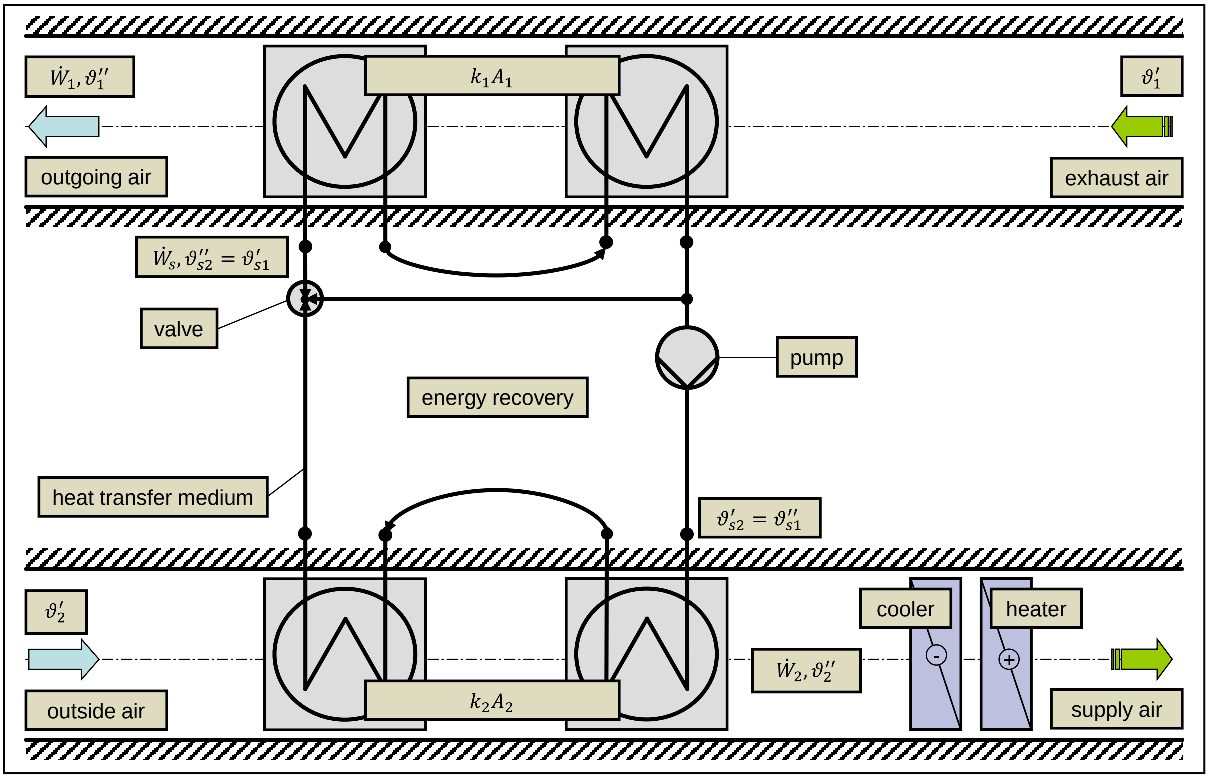


Figure 1: Sketch of an integrated circuit system in AHU and additional heater/cooler

$$\begin{aligned}\dot{W}_1 &= (\dot{m} \cdot c_p)_1 \\ \dot{W}_2 &= (\dot{m} \cdot c_p)_2 \\ \dot{W}_s &= (\dot{m} \cdot c_p)_s\end{aligned} \tag{1}$$

A characteristic of the heat transfer is given by the number of transfer units,

$$NTU = \frac{kA}{\dot{W}} \tag{2}$$

and the efficiency of the energy recovery system is represented by the recovered heat coefficient, defined for the supply air side, according to the European standard EN 308 [3]:

$$RHC = \frac{\vartheta_2^{"} - \vartheta_2^{'}}{\vartheta_1^{'} - \vartheta_2^{'}}. \tag{3}$$

In basic systems as shown in Figure 1, recovered heat coefficients of about 60% are common. The example in Figure 2 shows the characteristic relation between RHC and NTU for two different heat exchangers A and B. Here, the dotted line of heat exchanger B exceeds the continuous one of coil A, indicating a better performance with respect to heat transfer. This performance depends on e.g. the tube pattern and arrangement as well as the fin geometry and material. For a given heat exchanger tube pattern and constant air flow rates, larger RHC can be realized only by increasing the heat transfer area, which in general causes higher airside pressure drop and thus leads to higher ventilation power consumption. As can be seen in definition (2), NTU grows proportionally with the transfer area and thus with e.g. the number of heat exchanger rows. The same holds for the airside pressure drop, cf. Figure 3. Both RHC and pressure drop are taken into account by the AHU energy efficiency classes introduced by Eurovent Association [4]. This labeling system uses compensation weighting of various impacts such as thermal and electrical energy efficiencies and climate dependencies. It is based on the revised European standard EN 13053 [5].

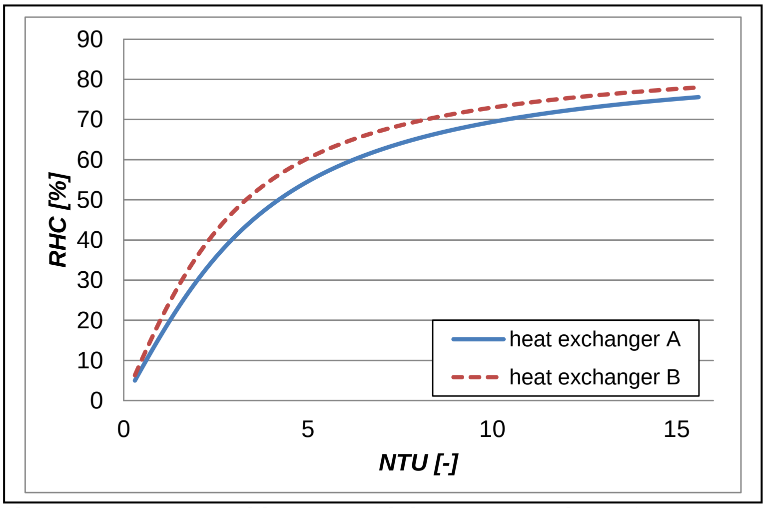


Figure 2: Recovered heat coefficient vs. number of transfer units (schematic)

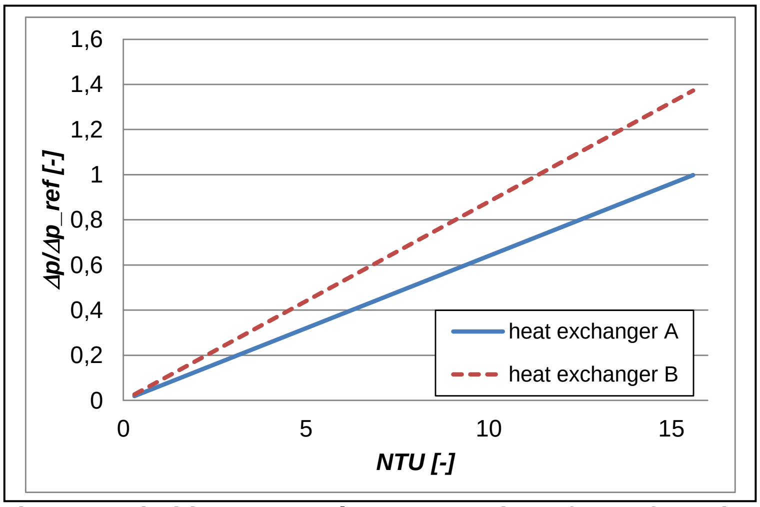


Figure 3: Airside pressure loss vs. number of transfer units (schematic)

The curves in Figure 2 show a generally valid progression with only small increase for large NTU. This means: the larger the number of rows, the smaller will be the gain in RHC by increasing the heat transfer area whereas the growth of pressure drop stays constant (Figure 3). All in all the energy efficiency decreases. If the goal is to recover a huge amount of energy, a large area is necessary which leads to smaller efficiency. In terms of energy efficiency, a smaller RHC may be favorable although less energy would be recovered. Dreher [6;7] defines characteristic parameters to predict and control the effectiveness of a RHC increase. Eurovent [4] suggests life cycle costs (LCC) analysis to evaluate optimal RHC. Thus the auxiliary energy consumption, which has a significant impact in some cases, could also be taken into account.

In the following we discuss results of LCC calculations according to VDI 2067 [8] considering two different energy recovery systems in an office building AHU which operates five days per week with operating grades as shown in Figure 4. Figure 5 displays the air inlet conditions. General parameters of the calculation are summarized in Table 1, further parameters depend on the system. All calculations were done using the design software Lplus [15]. The first system provides RHC = 67%, in the second case with heat exchanger area (here: number of rows) increased by 20% we have RHC = 77%. These values were calculated for standard inlet conditions according to EN 308 [3] and assumed to be constant during the observation period of fifteen years. In comparison to the first case increasing the number of rows on the one hand leads to higher airside pressure drop and higher costs for heat exchangers, AHU and fan. Beside the investment costs also the electricity costs increase because of higher ventilation power consumption. On the other hand there will be savings on the thermal energy costs side because more energy can be recovered.

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
op. grade [%]	100										x	x	x	x	x	x	x	x	x							
op. grade [%]	75								x	x										x	x					
op. grade [%]	50							x														x				

Figure 4: Operating grades of AHU in application “office building”

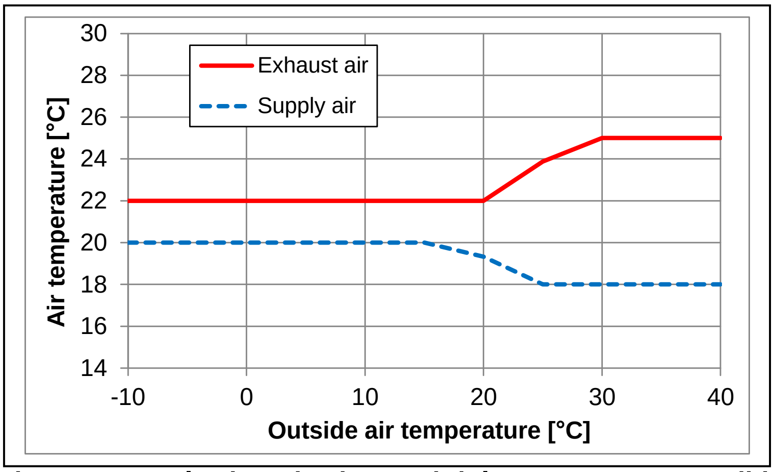


Figure 5: Supply air and exhaust air inlet temperature conditions

Table 1: Parameters of LCC calculations

location	Frankfurt
air flow rate $\dot{V}$	50,000 m³/h
external pressure drop	2*400 Pa
fan system efficiency η_{vent}	0.6
boiler efficiency η_{boil}	0.97
energy efficiency ratio EER	4.0
heating costs	0.06 €/kWh
electricity costs	0.15 €/kWh
observation period	15 years
interest factor	1.05
price change factor material	1.03
price change factor energy	1.05
maintenance	1 % of invest

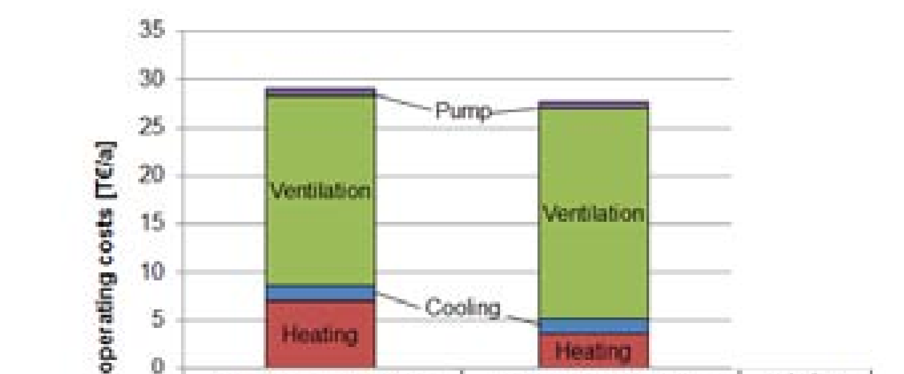
Considering the weather data of Frankfurt over a period of 8760 hours (i.e. one year) and taking the inlet temperature conditions, operating time and grades into account, the power consumption caused by heating was calculated according to the basic formula

$$\dot{Q}_{heat} = \frac{\dot{W}_2 \cdot \left(\vartheta_{SupplyAir} - \vartheta_2^{'}\right)}{\eta_{boil}}, \quad \textbf{(4)}$$

where $\vartheta_{SupplyAir}$ denotes the requested supply air temperature. In case of cooling the calculation is analogous with η_{vent} replaced by EER. The basic formula for ventilation power (pumps analogous) is:

$$P_{vent} = \frac{\dot{V} \cdot \Delta_p}{\eta_{vent}}. \quad \textbf{(5)}$$

Figure 6 shows a comparison of the resulting operating costs. In the second case these are slightly lower than in the first case (about 4%). Here, the growth of ventilation power consumption is over-compensated by the savings in heating energy. Taking the investment costs into account, we have a progress of AHU total payments as shown in Figure 7. The gradients of the two graphs represent the total annuity per year. Despite the before mentioned difference in the operating costs, it can be seen that over the observation period of 15 years system No. 1 with RHC = 67% (dotted line) outperforms the second system with RHC = 77% due to lower investment costs.



	energy recovery 67% operating costs [€/a]	energy recovery 77% operating costs [€/a]	relative Deviation [%]
Pump	706	803	13,7
Ventilation	19,604	21,733	10,9
Cooling	1,595	1,565	-1,9
Heating	7,063	3,631	-48,6

Figure 6: Comparison of operating costs in application “office building”

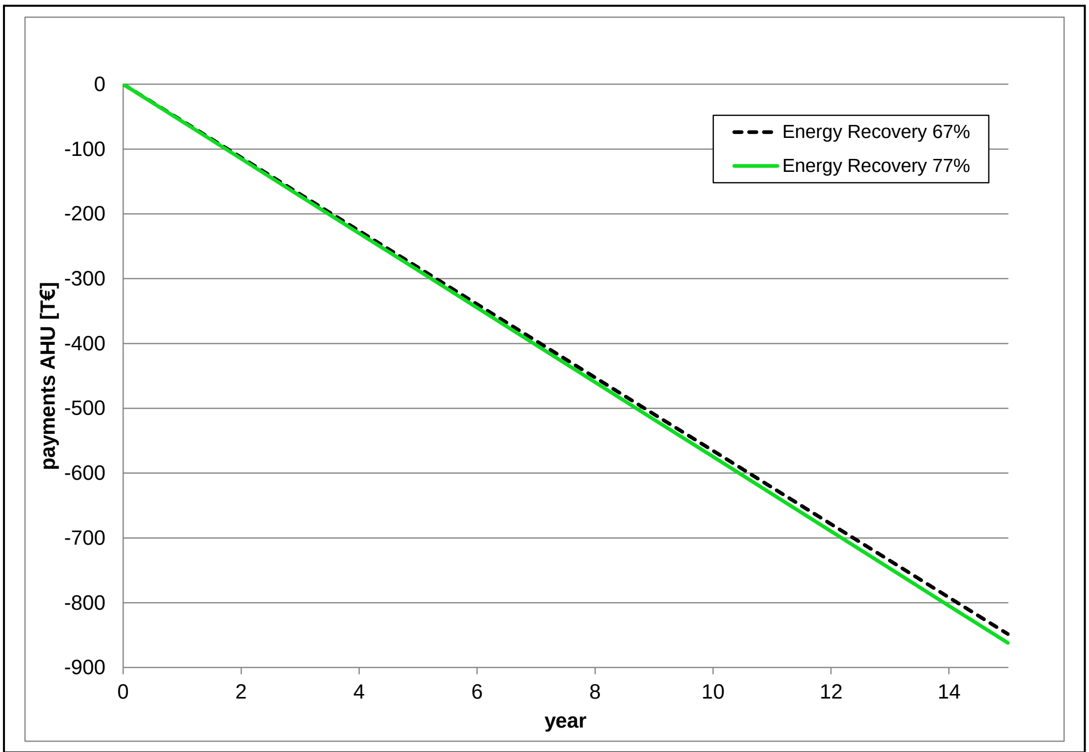


Figure 7: Comparison of payments AHU in application “office building”

We emphasize on the fact that the optimal RHC depends on the specific application as well as on location and energy costs. To investigate the application's impact on life cycle costs we show an analogous result for AHU energy recovery in a hospital with a 24/7 operating time and operating grades as specified in Figure 8. The parameters given in Table 1 and Figure 5 still hold. Figure 10 shows that from an economic point of view system No. 2 now outperforms system No. 1. As in the other application the operating costs are better (about 5%) but here the level of costs is much higher and thus the absolute difference, cf. Figure 9. This means: The relation between investment and operating costs has changed advantageously towards the case of RHC = 77%.

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
op. grade [%]	100						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
op. grade [%]	75	x	x	x	x	x																			x	x
op. grade [%]	50																									

Figure 8: Operating grades of AHU in application "hospital"

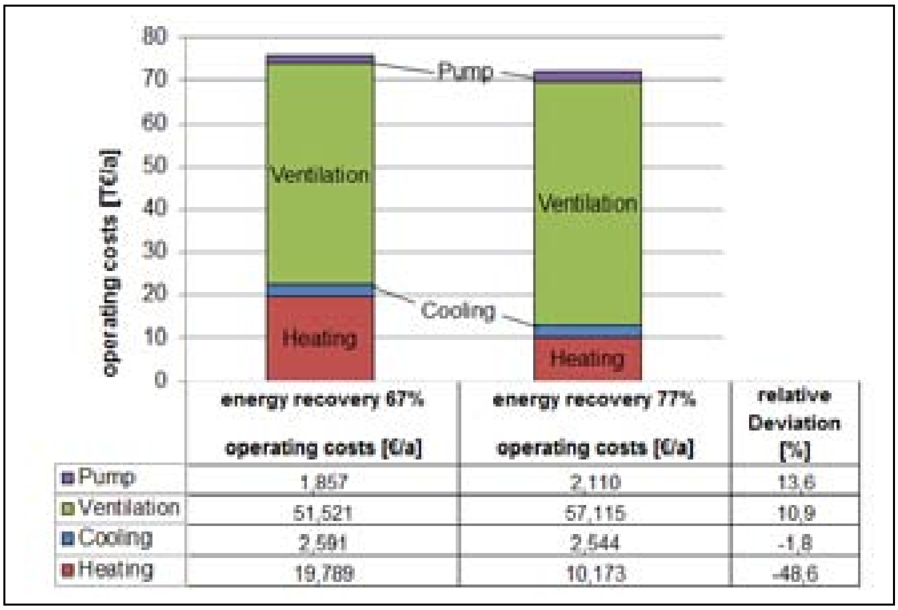


Figure 9: Comparison of operating costs in application "hospital"

Optimal Medium Mass Flow Rate

For given heat exchanger geometries and air flow rates the medium mass flow rate has to be optimized to provide maximum heat transfer. This task may become even harder if the air flow rates and/or geometries of the two air sides differ (e.g. filter preheating of outside air, different fin pitches or number of rows). In some manufacturers' integrated circuit systems [16] the mass flow rate will be adjusted in the control circuits to fulfill the relation $\dot{W}_{s,opt} = (\dot{W}_1 + \dot{W}_2)/2$. In the following we discuss the conditions under which this suggestion holds. Provided that the heat transfer medium circulates without losses and that there is no condensation in the air flow, the optimal heat capacity rate of the medium is given as [9;10]

$$\frac{1}{\dot{W}_{s,opt}} = \frac{1}{\dot{W}_1} \cdot \frac{(kA)_1}{(kA)_1 + (kA)_2} + \frac{1}{\dot{W}_2} \cdot \frac{(kA)_2}{(kA)_1 + (kA)_2} . \qquad \textbf{(6)}$$

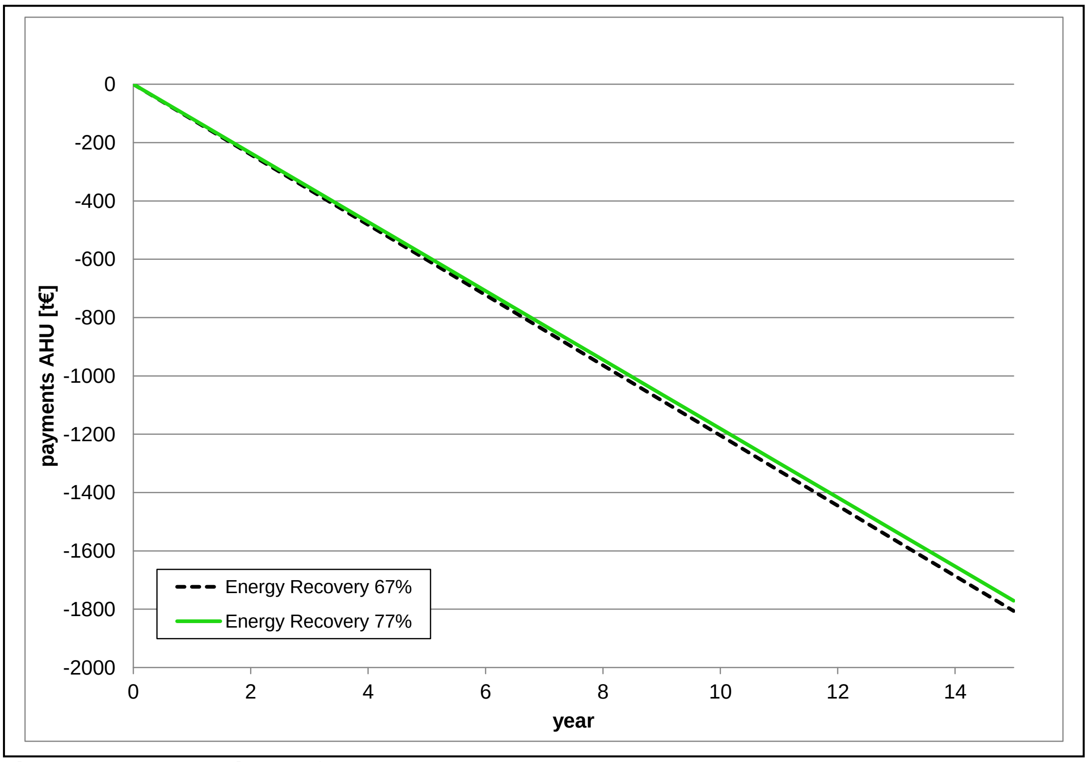


Figure 10: Comparison of payments AHU in application "hospital"

It can also be displayed as

$$\dot{W}_{s,opt} = \frac{\dot{W}_1 + \dot{W}_2 \cdot \nu}{1 + \nu}, \quad \textbf{(7)}$$

where ν denotes the NTU ratio,

$$\nu = \frac{NTU_2}{NTU_1}. \quad \textbf{(8)}$$

Since the overall heat transfer coefficient k and thus NTU itself depends on the heat capacity rates and on the temperatures, equation (7) in general cannot be solved explicitly.

Assumed that ν = 1 holds in the special case of identical heat exchangers on both air sides, we have

$$\dot{W}_{s,opt} = \frac{1}{2}(\dot{W}_1 + \dot{W}_2). \quad \textbf{(9)}$$

If in addition the supply heat capacity rate equals the exhaust air heat capacity rate (identical air flow rates, densities and heat capacities),

$$\frac{\dot{W}_1}{\dot{W}_{s,opt}} = \frac{\dot{W}_2}{\dot{W}_{s,opt}} = 1 \quad \textbf{(10)}$$

holds. Formula (9) is valid only for the special case ν = 1 but, as can be seen in the characteristic progression of Figure 2, variations in the NTU values only have small impact on the RHC if the RHC is large. This means in case of very efficient integrated circuit systems formula (9) can be considered as an approximate solution of the general equation (7) or as the initial value for an iterative solution, respectively.

Iteration might not be possible in case of control circuits. To maximize the transferred heat capacity at varying air flow rates and inlet conditions, the optimal medium mass flow rate has to be adjusted continuously. Moreover for multifunctional systems with feeding-in equation (7) is not valid.

Multifunctional Systems

The utilization of heat transfer media enables the realization of further thermodynamic functions along with energy recovery, e.g. integrated heating and cooling, filter preheating as well as the use of other available heat sources and sinks as for example chiller waste heat.

Feeding-in of heating (or cooling) energy in an integrated circuit system leads to a higher (or lower) fluid temperature. Thus the requested supply air temperature is provided without any additional fin coils, cf. Figure 11. The heat transfer medium will be heated (cooled) before entering the inlet of the supply air heat exchangers which operate in cross counter flow. This indirect heat transfer induces a slight decline of the recovered heat coefficient due to transport losses. The higher the RHC of a basic integrated circuit system is, the lower are the necessary feeding-in capacity $\dot{Q}_{in}$ and the losses [11;12]. This is the reason why basic systems with $RHC \geq 70\%$ (cf. [13;14]) are adequate to run with multifunctional use efficiently. An overview of this field of research is given in [12].

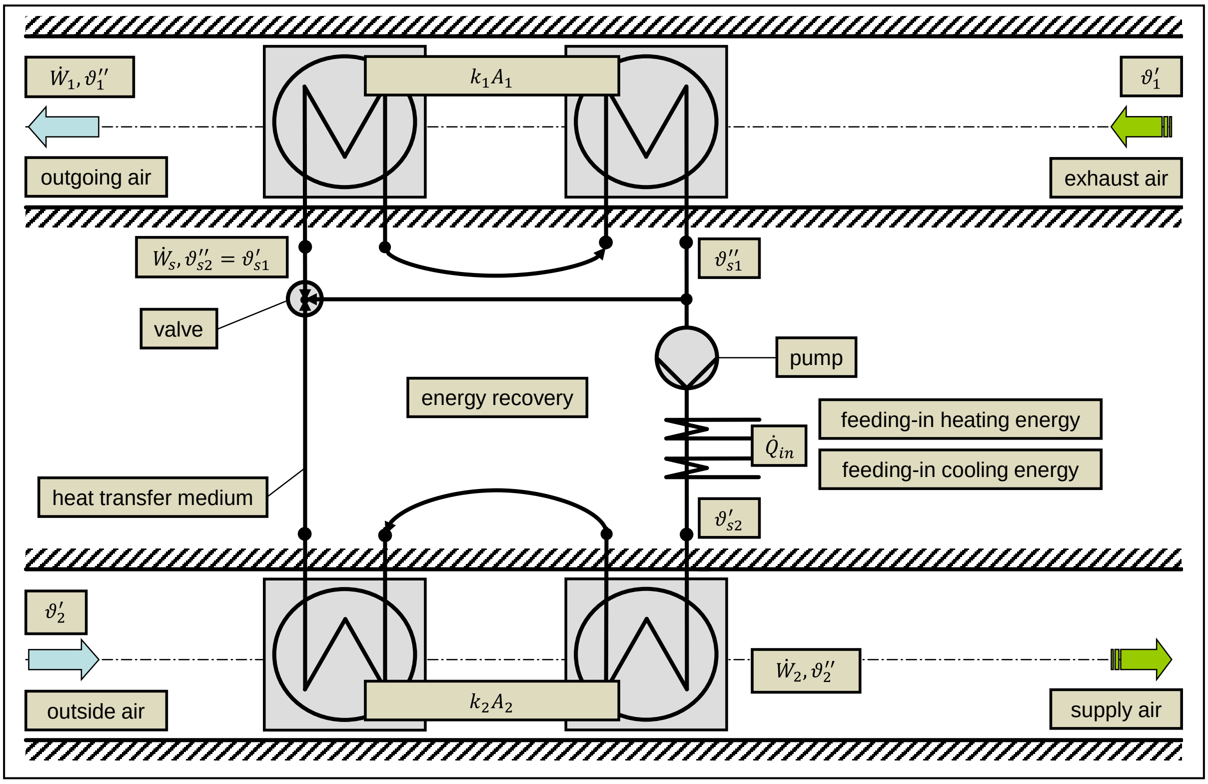


Figure 11: Sketch of a multifunctional integrated circuit system in AHU

We emphasize the fact that the RHC is not yet defined for multifunctional energy recovery systems. To demonstrate that definition (3) cannot be used to evaluate the efficiency of multifunctional systems, we consider the case where the desired supply air temperature provided by feeding-in is greater than the exhaust air temperature (cf. Figure 11),

$$\vartheta_2'' > \vartheta_1' . \quad \textbf{(11)}$$

Hence according to equation (3), we would have an efficiency that exceeds 100%:

$$RHC = \frac{\vartheta_2'' - \vartheta_2'}{\vartheta_1' - \vartheta_2'} > 1 . \qquad \textbf{(12)}$$

Therefore, it is more common to define the recovered heat coefficient for the exhaust air side,

$$RHC = \frac{\vartheta_1' - \vartheta_1''}{\vartheta_1' - \vartheta_2'} \qquad \textbf{(13)}$$

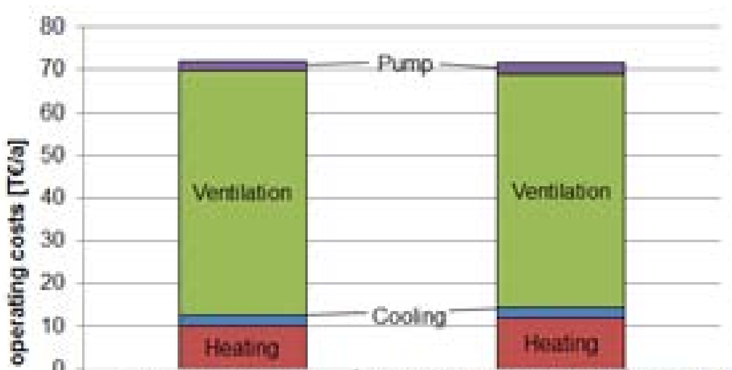
or to subtract the change in supply air temperature caused by the feeding-in capacity $\dot{Q}_{in}$. Provided that there is no condensation of humid supply air this capacity equals

$$\dot{Q}_{in} = \dot{W}_2 (\vartheta_2'' - \tilde{\vartheta}_2) , \qquad \textbf{(14)}$$

where $\tilde{\vartheta}_2$ denotes the outlet air temperature of the basic energy recovery system without feeding-in. This yields to an alternative definition of the recovered heat coefficient:

$$RHC = \frac{\tilde{\vartheta}_2 - \vartheta_2'}{\vartheta_1' - \vartheta_2'} . \qquad \textbf{(15)}$$

Feeding-in allows for a substitution of additional heaters and coolers by less expensive plate heat exchangers. Moreover, there is a smaller supply airside pressure drop and so the decrease of the amount of energy recovered is compensated in terms of overall energy efficiency. Furthermore, there are secondary savings due to a reduction of supply air handling unit length and, if applicable, the choice of a smaller and thus less expensive fan. The following LCC analysis examines these benefits of multifunctional systems. The left side of Figure 12 once again shows the operating costs of the above mentioned basic energy recovery system with RHC = 77% for application "hospital" (as displayed in Figure 9, right side). Based on this system we consider a multifunctional integrated circuit system with feeding-in for integrated heating and cooling. Here, the additional supply air side heater and cooler were replaced by two plate heat exchangers while the fans remained the same. Because of the transport losses mentioned above the RHC is reduced to 75%, calculated according to equation (15).



	energy recovery 77% operating costs [€/a]	multifunctional system 75% operating costs [€/a]	relative Deviation [%]
Pump	2,110	2,532	20,0
Ventilation	57,115	54,461	-4,6
Cooling	2,544	2,553	0,4
Heating	10,173	12,035	18,3

Figure 12: Operating costs of multifunctional system in application "hospital"

The right side of Figure 12 displays the operating costs of the multifunctional system. The ventilation power consumption decreases due to less pressure drop on supply air side. This corresponds with a decline in the operating costs, as shown in Figure 12. The internal pressure drop and thus the electrical power consumption of the pump rise because of the additional plate heat exchangers. The reduction of RHC leads to a small increase of thermal energy costs because less energy is recovered which means more heating/cooling is required. All in all the total operating costs of this multifunctional system are nearly the same as in the case of the system without feeding-in. Comparing the investment costs we have a difference of about 10,000€ which means a reduction of about 5.5% for the multifunctional system. This amount could have been even larger if a smaller fan was used. The AHU total payments of both systems are investigated in Figure 13. It can be seen that the multifunctional system (dotted line) outperforms the basic system. Moreover the length of AHU has significantly decreased as can be seen in Figures 14 and 15. This benefit of multifunctional systems is especially important in AHU revitalization projects where the available space in the building is limited.

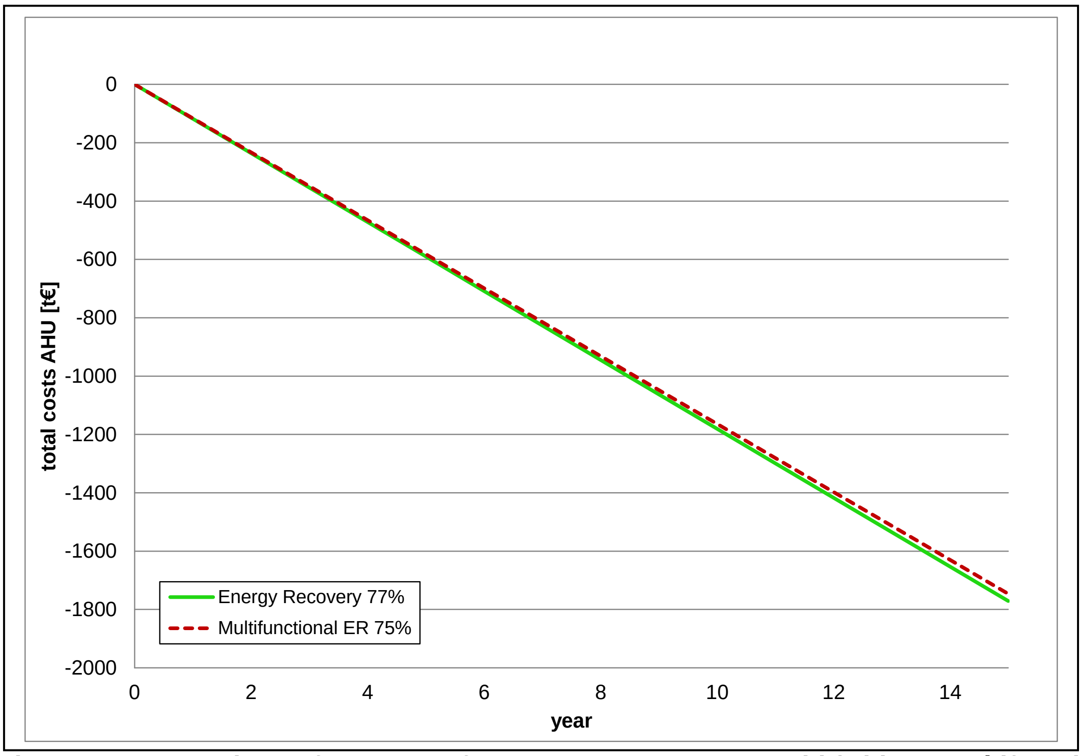


Figure 13: Comparison of payments for energy recovery AHU with/without multifunctional use

Summary

In this paper main aspects of efficient energy recovery were investigated. The first question considered was which recovered heat coefficient is optimal with respect to the customers' requirements. It was provided by means of life cycle costs analysis that the answer to this question depends on the application. There are applications where smaller RHC values may be preferable while larger values lead to a decrease of energy efficiency. The optimization also depends on the location and the energy prices.

To optimize an integrated circuit system's efficiency the medium mass flow rate has to be thoroughly adjusted. We analyzed the equations given in literature to calculate the optimal mass flow rate that provides the maximum heat capacity transferred. In general cases this equation cannot be solved explicitly. Iterative solutions are possible, but might not be applicable within control circuits.

Multifunctional systems are integrated circuit systems with further thermodynamic functions such as feeding-in of energy. Using the example of integrated heating and cooling, the benefits in comparison to basic systems are demonstrated by means of a LCC analysis. This benefit depends on location, application and availability of external heat sources and sinks.

Figure 14: Drawing of the AHU with basic energy recovery system

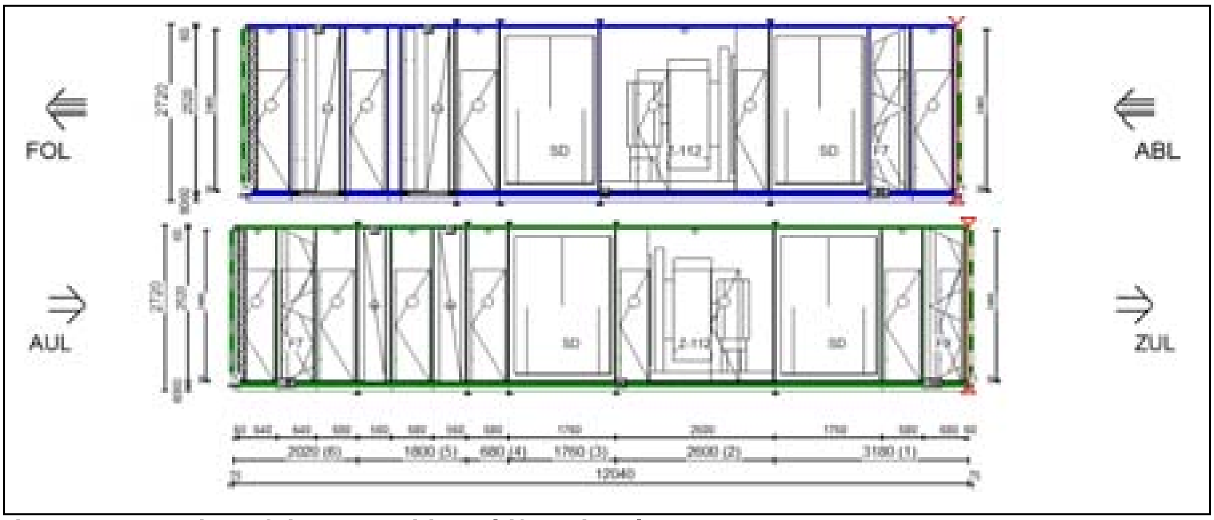


Figure 15: Drawing of the AHU with multifunctional system

References

[1] Nobis V. *Wärmeübertrager – Als Maßanfertigung am effizientesten*. HLH 61 (2010) No. 4, pp. 54-57

[2] Heß R. *Wärmerecycling auf höchstem Niveau. Hochleistungskreislaufverbundsysteme in der Anwendung*. cci 01/2010

[3] EN 308:1997-06 *Heat exchangers – Test procedures for establishing performance of air to air and flue gases heat recovery devices.* 1997

[4] Eurovent Certification Company *EUROVENT Operational Manual for the Certification of Air Handling Units*. OM-5-2009, Issued October 2009

[5] EN 13053:2012-02 *Ventilation for buildings – Air handling units – Rating and performance for units, components and sections.* 2012

[6] Dreher E. *KV-Wärmerückgewinnung nach neuen Richtlinien und Normen.* HLH 61 (2010) No. 8, pp. 29-33

[7] Dreher E. *Gesichtspunkte zur Optimierung der KV-Wärmerückgewinnung in RLT-Anlagen.* HLH 62 (2011) No. 2, pp. 32-36

[8] VDI 2067 Part 1:2000-09 *Economic efficiency of building installations – Fundamentals and economic calculation.* 2000

[9] VDI-Wärmeatlas. 9th edition, 2002, *Berechnung von Wärmeübertragern.* p. Ca14

[10] Roetzel W. *Thermische Auslegung von Wärmeübertragersystemen mit umlaufendem Wärme-träger*, BWK 42 (1990) No. 5, pp. 254-258

[11] Jüttemann H. *Wärme- und Kälterückgewinnung in raumlufttechnischen Anlagen.* published by Werner Verlag, 5th edition, 2001

[12] Kaup C. *Mehrfachfunktionale Hochleistungs-WRG-Systeme – Teil 1.* Die Kälte + Klimatechnik 1/2011, pp. 34-37

[13] VDI 2071:1997-12 *Heat recovery in heating, ventilation and air conditioning plants.* 1997

[14] VDI 3803 Part 5:2011-04 (Draft) *Air-conditioning, system requirements – Heat recovery systems (VDI Ventilation Code of Practice).* 2011

[15] http://www.gea-airtreatment.com/L-i-plus-i-Software.281.0.html?&MP=279-5897

[16] http://www.howatherm.de/web/DE/products/highefficiencyheatrecovery_products/hpwrg/

Energy efficiency in Data Centres: case studies, guidelines and educational experience from the IEE-PrimeEnergyIT research project

Andrea Roscetti, Lorenzo Pagliano
eERG, end-use Efficiency Research Group
Energy Dept., Politecnico di Milano

Alexander Schlösser
Technical University Berlin

Laurent Lefevre
INRIA

Vanessa Hübner
Berliner Energieagentur

Carlos Patrão
ISR-University of Coimbra

Bernd Schäppi, Thomas Bogner
Austrian Energy Agency

Abstract

The dynamic development of IT performance in conjunction with an increasing utilization of IT services in public and private sectors is resulting in growing energy consumption of centralized IT equipment in data centers. EU and US studies [1][2] indicate a strong increase with respect to the energy consumption of data centre IT and support infrastructure during the last years.

Experts agree that with growing demand for IT-services, centralized IT and data traffic will even more rapid increase and with that very likely the data centre's energy consumption as well. According to latest information from study on amended working plan for ErP[1], the energy consumption allocated to server and data storage equipment within the EU 27 is approximately 104 TWh/a [2].

Energy efficiency measures in context of data centres today are still focusing mainly on the cooling and power supply infrastructure. The Intelligent Energy Europe project PrimeEnergyIT has the objective to enhance the market demand for energy efficient IT in data centre, including server, storage and network equipment as well as new cooling and power management technologies.

Although the energy saving potential for IT-equipment is well known, the practical implementation is particularly in small and medium size data centre still in an early stage. Therefore PrimeEnergyIT supports IT- and facility manager by providing guidance for the planning and procurement of efficient data centre solutions. The project developed extensive information and training materials, including guidelines and collections of latest best practice examples. As part of the project over 300 IT-experts were trained in workshops all over Europe as an active measure to enhance energy efficiency in the field of data centre.

---

[1] See http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/index_en.htm

[2] Based on: 2nd stakeholder meeting Background study for the Amended Ecodesign Working Plan 16 September 2011, Bruxelles.

State of the art for data centre efficiency

The energy consumption of centralized IT-equipment and data centres has been a fast growing topic over the past few years. Major awareness originally came from data centre infrastructure level as limitations regarding power supply and cooling became apparent. Market forecasts and scenario analysis of different studies expected a doubling of energy demand within a few years unless effective energy saving measures were put into place [1]. It was also realized that a number of effective measures existed that in many cases would allow energy savings of 20-60% or even higher. Detailed measurement campaigns and assessments started between 2005 and 2007 resulting in the publication of a few highly recognized studies in Europe [3] and the United States [4]. The motivation for these investigations was manifold. The server and data centre performance increased rapidly while at the same time the energy prices surged as well.

The situation led to several international initiatives which have been started to address energy efficiency in data centres such as, the EU-Code of Conduct for data centres, “The Green Grid”, the Blue Angel and the Energy Star Programmes. The implementation of energy efficiency criteria, benchmarking tools, and efficient products, have been proposed to improve the efficiency at hardware and at infrastructure level. Many companies already started to implement energy efficiency strategies. Recent studies have indicated that this activity has already led to a positive trend. Compared to earlier scenarios from 2007, which indicated a doubling of energy consumption in 4-5 years, worldwide energy consumption of data centres has only increased by about 56% between 2005 and 2010 [3].

The slowed growth rate appears to be a result of already implemented simple energy savings measures for cooling and airflow optimization as well as the improved efficiency efforts for the facilities [3], nevertheless there is still high potential for further efficiency improvement especially for server rooms and medium size data centres.

Metrics and benchmarking

As a first step PrimeEnergyIT analyzed the existing metrics for data centres and IT-equipment. An energy-efficiency metric is typically used for benchmarking the energy consumption of single products or products systems. The complexity of the product system “data centre” is without doubt a challenging factor here. It is therefore not surprising that in the recent past a variety of metrics have been developed with the intention to quantify selected aspects of the data centre. At the present we recognized two main categories of energy-efficiency metrics.

Equipment-level metrics, with selected metrics for server, storage, and network equipment.

Facility-level metrics, which is basically one metric that correlated the energy consumption of IT-equipment against the infrastructure or overall data centre energy consumption like the Power usage effectiveness (PUE) or Data centre power effectiveness (DCPE)

Such facility-level metrics are essential to compare the overall improvement of energy efficiency. The PUE metric opened the door for detailed energy measuring campaigns. These campaigns resulted in improvement processes and helped to raise the awareness along the whole value chain. At the present time, the PUE metric is reaching its limits. Therefore main focus related to the ongoing development of equipment-level metrics. PrimeEnergyIT supports the application of such metrics for IT-manager and public authorities. Data centre manager should use these metrics for comparison of individual IT-equipment and to ensure the procurement of the most efficient equipment.

Servers

Servers are typically responsible for 30-40% of the total energy consumption in data centres. Consequently energy efficient approaches for this technology are essential to achieve substantial savings. Optimization of server systems can serve several goals in parallel by allowing simultaneous reductions in demand for power, cooling capacity, space and management. This could also lead to significant cost reductions during operation. The most common and effective approaches are:

hardware consolidation, consolidation by virtualization, use of most energy efficient hardware and power management at the system level.

Storage

Information is at core of any business. It is not surprising that the storage needs organizations are expected to grow by up to 60% per year through 2020 [6]. With the prices of storage falling, it has become easier not to delete data and to add additional capacity as required, rather than spend time discovering which data can be removed. However, as the digital waste in data centre storage grows and limits are reached, efficiency is a word that is increasingly welcome. Studies show that large enterprises are faced with the difficult task of providing sufficient power and cooling capacity, while midsize enterprises are challenged with finding enough floor space [7] for their storage systems. As data storage is expected to be responsible for a large part of the energy consumed by data centres over the next years, it is crucial to make storage systems more energy efficient.

Networking

The energy consumption allocated to switches, routers, and other networking equipment is approximately 8 to 12 percent of the total data centre's energy footprint. Due to this rather low percentage of the total energy demand, networking equipment has not been in the focus of improvement measures. The IT world is currently in the middle of a tremendous shift towards a centralized production of applications resulting in new traffic volumes and patterns. By utilizing Software-as-a-Service and Cloud Computing, applications and traffic is produced in data centrs, which increases the influence of network technology to the overall efficiency. The power consumption of network equipment varies according to the equipment's performance features, form factor, rack integration and cooling as well as the selected power supply. With respect to the overall energy consumption of the network the implemented network architecture, cabling solution, together with the defined service requirements also plays a significant role.

Cooling systems and power distribution

More than 99% of the electricity used to power Information Technology equipment is normally converted into heat due to the Joule effect. Additional energy is required to remove this heat to ensure appropriate operation of IT equipment. The heat to be dissipated comes from Uninterruptible Power Supplies (UPS), power transmission units, IT equipment, lighting system, human bodies and the cooling equipment itself. In theory, the IT loads should be easy to evaluate, which should enable to design and size the cooling equipment correctly. Energy efficiency in data centres and server room infrastructures became a major issue for IT and infrastructure management only a few years ago: in the last 10 years the electricity cost has increased, and is expected to continue to rise.

In some cases, electrical energy costs account for 40-50% of the total data centre operation budget [8]. Cooling capacity, together with power availability, is one of the more serious constraints on the future growth of an IT infrastructure.

Data collection for efficiency evaluation

Data centres are complex environments that house a wide variety of energy consuming equipment. Comprehensive energy monitoring is essential as a basis for the stimulation and the evaluation of effective energy saving measures. Lack of energy data is currently a major barrier for effectively targeting energy efficiency measures. Most data centres are not equipped with advanced electric meters and monitoring systems that accurately measure and report energy consumption [2].

Better data availability would help highlight the importance of energy-efficiency improvements and facilitate rightsizing of power supply and cooling. It would also allow data centre operators to monitor and evaluate the savings resulting from specific efficiency measures, providing the information basis to effectively implement further improvements.

Monitoring approaches should be carefully designed to ensure maximum usefulness of data for performance assessment and decision making. The primary objective should be to have "the right data" available.

The main objectives of the PrimeEnergyIT project

The project has three major objectives to be addressed by appropriate measures in the timeframe of the action:

Facilitating energy efficient hardware selection and management by the development and implementation of hardware and service based on objective energy efficiency criteria and metrics. The criteria, metrics and benchmarks are central basic elements for several market instruments implemented within the project (e.g. education, best practice, certification)

Promoting the use of energy efficient technology by evaluation, demonstration and dissemination of efficient central IT and cooling hardware, including best practice (partly presented in this paper)

Supporting a broad dissemination and implementation of energy efficient solutions in the market based on education, public procurement, certification and promotion.

The following best practice cases mainly focused on cooling and airflow optimization, free cooling as well as energy efficient storage and network optimization.

Case studies – best practices

Free cooling adoption - Laboratório de Computação Avançada (LCA), University of Coimbra (UC), Portugal

The "Laboratório de Computação Avançada" (LCA) of the University hosts one of the most powerful supercomputer in Portugal, "Milipeia", and provides CPU time to research projects for scientists from 14 Universities and Research Institutes in Portugal. Researchers from FCTUC have been actively engaged in research, which requires High Performance Computing (HPC): Condensed Matter Physics, High Energy Physics, Lattice QCD, Quantum Chemistry and Protein Folding/Unfolding. Condensed Matter Physics researchers are co-developers of OCTUPUS, a widely used TDFT code that is now part of the PRACE benchmark suite.

The floor area of the data centre is 66 m^2, populated with 132 servers with an electrical load of 66,3 kW. A free-cooling system of about 170 000 BTU/hour is installed. When the outside temperature is below the inside temperature (mostly at night and/or in winter), cold ambient air is drawn inside the data centre to accomplish cooling while the conventional mechanical chilling system is off (or in standby). Fans, humidifiers or dehumidifiers and controls are the only power consuming components, making airside economizers a great opportunity for energy saving.

The measurement concept is based on an energy consumption monitoring (15 to 15 minutes during one week). The measurement points for energy consumption were the data centre panel board and HVAC panel board.

The equipment was 100 % financed by a measure of the Portuguese utility within the scope of the DSM Portuguese program. The costs of installation of the system were at about € 6 040 (50 % financed by the measure).

The simple payback was about one year taking into account the financial incentive. Without the incentive, the return is about two years.

Energy efficient storage and network optimization - Postbank, Germany

In 1996 the Postbank set up its backbone based on ATM technology (Asynchronous-Transfer-Mode) and has extended it continuously ever since. The backbone reached the end of its life cycle in 2007. Additional expansion could only be realized by increasing complexity and expenditures, which was not appropriate from an economic and technological point of view. Therefore the project "New Backbone" was initialized, aimed to evaluate and implement new technologies.

In this project, a backbone based on MPLS (Multi-Protocol-Label-Switching) has been chosen. A network based on this technology offers optimal characteristics to meet the high requirements of Postbank IT and also improves the energy balance considerably. For the Postbank, as an ISO 14 001 certified enterprise, low energy consumption is an important criterion for the selection of new technologies. With the MPLS technology a physical network is divided into logical, independent subdivisions or clients. This virtualization meets increased demands in terms of scalability and easy network management, as well as protecting data connections from unauthorized access.

Improvements and results

The new flexible and encrypted backbone was introduced in early 2009. As an "early mover" the Postbank set standards in the banking sector.

After the introduction of the MPLS backbone, network components in the data centre were removed and replaced with new components step by step. These components, and the associated change in technology, provide different logical networks and even network ports, while the old technology made use of dedicated hardware and electric lines. Thanks to the subdivisions that the new system allows, necessary hardware could be reduced dramatically at all sites. While the old data centre and branch system required approximately 400 routers and switches with a power consumption of about 1 438 480 KWh p.a., the visualized network needs only 188 network components which consume about 588 234 KWh p.a., resulting in energy savings of over 59 %.

Furthermore, the introduction of logically separated networks made decentralized firewall-transitions redundant. This measure reduced energy consumption from 63 072 to 24 528 KWh p.a., over 61 % of energy savings for firewall servers. The last phase of the virtualization process will be concluded in the end of March 2012. The last dedicated distribution network components of the Postbank development network will be removed until then. This step will create further energy savings of over 52 % or 170 820 KWh p.a. compared to today's distribution infrastructure.

Combined, the application of these new technologies reduced the energy consumption in the affected areas by 1 059 610 kWh p.a. or 58 %.

Compared to the relatively long operation time of network equipment the most important economic value of performed measures beside a quick "return of investment" was the reduced energy costs due to energy savings of 58 %. In respect to the improved security and increased availability this results in a significant marketing potential on the provided services.

Summarized important aspects:

New network equipment with life cycle of 10 years

Return of investment is less than 18 months

Switch replacement is linked to server life cycle due to soft migration

Server virtualization in combination with further cooling measures, regio iT Aachen, Germany

As an IT service provider, regio iT Aachen is partner for municipalities, local businesses, energy trading companies, waste management companies, schools, and non-profit organizations.

regio iT Aachen operates the IT and associated infrastructure. In addition a small amount of the space is leased. The data centre building has secondary uses that had been excluded in the energy analysis.

Description

Based on energy monitoring, the energy to operate the data centre has been monitored continuously since 2007 at regio iT. The data centre has an area of 220 m^2 with about 480 servers, 150 kW of electrical load, an annual IT power consumption of 1 250 000 kWh and an infrastructure power consumption of 640 000 kWh (power distribution, air conditioning, etc.). The share of the IT equipment to the total power consumption is approximately 65 % (which equals to an average PUE of 1.5).

The data centre is part of an office complex and consists of 6 server closets. The useable IT area of 220 m^2 was operated at full capacity in 2009. The data centre had more than 50 racks and about 480 servers at a nominal electric capacity of the total IT of 155 kW. When operated at full capacity, the limits of the cooling system are reached. The power density of the IT was 1 kW/m^2 relative to the area of the server closets. The IT infrastructure power consumption increased more than 25 % within one year.

The power density was with 5 000 kWh per m^2 ;an upper limit compared to other data centres. The average installed capacity was 300 W per server.

The data centre is not currently equipped with free cooling. The energy efficiency ratio (EER) of the air conditioning was comparably poor (EER = 2).

The availability levels of the data centre are comparable with Tier II requirements. Some components meet Tier III requirements.

The energy monitoring data was analyzed in detail with the scientific support of TU Berlin. The results shows that the existing cooling equipment was used to capacity and further development of the IT would not have been possible with the existing infrastructure. The in and out air-temperatures of the recirculation air system were very low. Due to unnecessary mixing of the warm and cold air in the corridors between the racks, the cooling effort was too high. In addition, the very low temperature of the cooling water led to the chiller operating at a poor EER.

Improvements

In two rooms, specific efficiency measures were planned and set into action based on the 2009 analysis. The rack areas not in use were closed with cover plates. The incoming airflow from the raised floor was optimized.

Next, the in- and outflow temperatures of the circulation air cooling system were raised step-by-step from 14/21 °C to 16/24 °C. As a result, the air cooling circulation devices could be operated with a higher temperature spread (delta T = 6/7 °K). The efficiency of the heat transmission improves significantly. The increase of the in- and outflow temperatures in the chiller can be seen as a further efficiency potential, which is not captured at the moment but should be addressed in the future.

For the room with the highest power density and cooling bottleneck a cold-aisle-containment was installed which resulted in far better separation of hot and cold air in the server room.

To prepare further measures, additional measurement instrumentation was installed to detect the rack temperature at 36 measuring points, and to determine the flow rates and temperatures at 5 points in the raised floor.

From 2008 to 2010, the IT infrastructure was shifted to about 500 physical and 750 virtual servers. The energy demand of 150 kW could be kept constant due to the accompanying measures to optimize the cooling.

The number of IT services and applications could be increased significantly with improved cooling and virtualization without further interference in the data centre infrastructure.

Results

Due to intelligent combination of virtualization and improved cooling, the data centre runs far more IT services and applications than in 2009 at about the same power consumption, despite the fact that the cooling equipment was already operating at full capacity in 2009. The productivity of the data centre could be improved with no overall increase in electricity cost.

Due to the virtualization, the better capacity utilization of the IT also leads to a better utilization of the UPS. The losses decrease compared the electricity demand. The ratio of physical to virtual servers increased from 480/120 to 500/750 while maintaining the power demand stable at 150 kW.

The efficiency gains described above are not reflected in the PUE, since this is not directly linked to the actual use of the IT. Due to temporary parallel use during the virtualization shift, the PUE even increased for a short time. The capital cost for the improved cooling was less than € 25 000. The payback period is less than 1 year based on the electricity cost reduction of about 15 %.

Improvement of air flow and humidity, Laboratoire de Physique Subatomique et de Cosmologie (LPSC), France

Description of the system

The IT-services for the laboratory include web, mail, external access, databases and storage. Most of the services are virtualized with VMWARE (3 vmware servers, power supply redundancy, servers powered by an UPS (30 kVA)).The resources for LHC computing grid (WLCG) : LPSC provides resources for WLCG at tier 2 centre. (700 cores, 700 Tb (gross))

The LPSC computing room uses dual mode free cooling: For the 85 % of the time when the external temperature is less than 25 °C, direct air free cooling can be used and for the remaining time water-air free cooling is used.

The principle of direct air free cooling is quite simple. To cool the production servers and storage when the external temperature is lower than 25 °C, which is about 85 % of the time at Grenoble, air is drawn from outside and is used directly to cool the servers. The air coming from the rear of the servers is then blown back to the outside. There is a complete separation of hot and cold airflow which is the principle of cold aisle systems.

When the outside temperature is too low, in this case lower than 13 °C, a recycle valve injects some of the hot air from the rear of the cabinets mixing it with outside air to regulate the input temperature to 13 °C.

Water-air free cooling is active when the outside temperature is above 25 °C: the air is still taken outside to cool the servers but it is first cooled down to 25 °C by a simple water-air exchanger. Cold water is pumped from groundwater and passed through a direct water-to-air exchanger without need for a compressor.

The first aim of controlling the airflow was to remove the maximum amount of heat. The airflow into the system from outside is equal to that of the hotter air evacuated. For a given airflow, the amount of heat evacuated depends on the temperature difference between the in-flow and the out- flow. It follows that the outgoing air should never be mixed with cooler air before evacuation as this will reduce the temperature difference, and the heat dissipated by the system will be reduced.

The second aim of controlling the air flow was to have a uniform temperature in the cold corridor. As explained above, we wanted to use direct air free cooling as long as the incoming air has a temperature of less than 25 °C. We discovered that it is very important to make sure that the temperature in the cold corridor is uniform. In the original system there were areas where the temperature was observed to be up to 7 °C higher. To ensure correct cooling, we were obliged to lower the transition temperature accordingly, thus reducing the range over which direct air cooling could be used, since in Grenoble the outside temperature is below 18 ºC only 60 % of the time.

Airflow is controlled by partitions around the cabinets separating the cold corridor from the rear of the cabinets. Any rack with no equipment was fitted with blanking panels. The sides of the cabinets were insulated with foam strips. This was sufficient to remove the hot spots described above.

For humidity control, the first point to consider is that modern hardware is much more robust than it was only a few years ago. Wider temperature and humidity ranges are acceptable. Furthermore, rapid advances in technology lead to renew equipment for both performance and power consumption improvements as often as every three years, and it is rarely over 5 years old. In consequence equipment is replaced before any significant degradation.

Exceptions to this are magnetic tape units, which need a regulation of the humidity, nonexistent at the LPSC since backups are exported to the CCIN2P3 via the network. Tape units need better control of humidity than that provided by free cooling, an additional reason to consider retiring them.

Both upper and lower limits of humidity must be considered. A high level of humidity can lead to condensation, and when too low, electrostatic problems may be observed.

Condensation can occur when the external humidity is high and the external temperature is high. When the external temperature is such that we must cool the air before sending it over the servers it is possible that we reach the saturation point of the air. But this is only observed at the position of the water to air exchanger, which is the coolest point. Everywhere else the temperature increases and so the humidity decreases. The problem was simply solved by adding a condensate recovery at the water-to-air heat exchanger.

No malfunctions due to static electricity were observed. If they do occur, the remedy would be to place the cabinets and racks on a grounded anti-static floor, and ensure that they are individually grounded.

Since March 2008, LPSC experienced no interruption of production associated with the cooling system. At the beginning of the project because of a delay in the availability of the water-air exchanger and the blowing system, the LPSC did operate during March and April without it. This showed that the servers were able to draw air from outside using only their own fans.

In summer 2010 during building work on the site, an excavator cut the water inlet pipe. The outside temperature was 25 °C and, thanks to direct air free cooling, data services were able to continue until the pipe was repaired.

Any problem with the cooling has no impact on services if temperature is below 25 °C: 85 % of the time. Such a problem will have a small impact 13 % of the time when the temperature is between 25 °C and 33 °C since servers can operate up to 33 °C without damage. Free cooling allows saving more than 90 % of the energy necessary to cool the room compared to conventional means.

Energy use

The server and storage electrical consumption is currently 60 kW, the fan power is 2 kW for an air flow of 16 000 m^3/h, the maximum fan power is 3 kW for a maximum air flow of 23 000 m^3/h

Using the water-to-air exchanger, the maximum water flow is 20 m^3/h. At LPSC water is pumped for the use of several experiments, not only for the cooling of the computing. The pumping power, when using the water-air exchanger, is estimated to be below 3 kW. Electrical consumption for cooling 60 kW is 2 kW for the 85 % of the time in direct air free cooling mode, 5 kW the 15 % of the time in water-air free cooling mode. The average cooling power for 60 kW is reduced to 2.45 kW resulting in a cooling cost of only 4 % of the total electrical consumption.

Refurbishment of the Business Continuity data centre, Esselunga, Italy.

Esselunga S.p.A. is an Italian retail store chain. It was the first supermarket chain in Italy and was the first to introduce online shopping and self-produced organic products.

Description

The data centre room has about 190 m^2 of space and with an electrical load of 80 kW. It has all the typical IT components for a data centre including more than 110 servers, along with storage, network, power supply and continuity equipment. UPSs are also installed in the data centre, due to space constraints of the building that hosts it. The services operated are mainly databases, data storages, application servers and basic infrastructures services (mail, file servers,…).

Improvements and results

The business continuity data centre received an overall assessment made by HP at the beginning of 2010. In the middle of 2011 several improvements were carried out. First of all the room was reconfigured into hot/cold aisles, moving the air tiles in the cold sections and mounting the blanking panels with the re-orientation of both racks and appliances accordingly to the air flow direction: an operation that provides better environmental conditions for the IT loads. At the same time the distribution of rack electrical loads was optimized. The high power consumption devices were moved closer to the coldest air flow, typically in the lower part of the racks.

The whole cabling system was rearranged: all the cut-outs, possible shortcuts between hot and cold aisle, were sealed such that the cold airflow in the sub-floor is less obstructed.

In a second step, the UPS configuration was optimized. The existing three power continuity units were performing at low load levels. One became a backup unit, and the other two are now working at their optimal level, or at least at 50 % of nominal load.

In a final step, the positioning of sensors for CRAH control was corrected to be away from lighting fixtures and other disruptive loads. The optimization process was completed gradually with fine-tuning of air temperatures. The cooling load resulting from this renovation process is greatly reduced. Four CRAH units were working at full load before; now only three are actively working at significantly reduced power. The 4^{th} is now available as a stand-by unit.

In the last months the aisle containment structure was installed. Monitoring is now in progress and will provide additional data for a better evaluation of the whole process. All interventions were made without significant investment on specific hardware or equipment, excluding the containment panels, the only measure carried out by an external provider. The IT personnel of Esselunga took charge of all improvements during the normal maintenance operations, planned in three months. For these reasons it is not possible to have a simple evaluation of payback of these improvement measures.

The gradual development of efficiency measures also worked as a training experience in energy efficiency for the personnel involved (IT and technical services divisions).For Esselunga these skills and competences gained are clearly valuable, even if difficult to measure and quantify.

Conclusions

It is expected that the PrimeEnergyIT project will support all the energy efficiency in the data centre arena through increasing the awareness of all actors involved in the market.

The case studies results collected so far [9], along with the ongoing activities of training, the workshops conducted in all participant countries, and the development of guidelines both on public procurement and efficiency assessment are showing promising results and a growing interest in the topic.

The next development in the framework of the project will be to develop and implement an internationally accepted energy efficiency standard for central IT equipment. This would help professional buyers beyond the hardware level metrics already in development.

References

[1] E-server project website: http://www.efficient-server.eu/

[2] U.S. Environmental Protection Agency (EPA), ENERGY STAR Program, *Report to Congress on Server and Data Center Energy Efficiency, Public Law 109-431. s.l.* August 2007. Available on-line at http://hightech.lbl.gov/documents/data_centers/epa-datacenters.pdf

[3] Koomey J. *Growth in Data centre electricity use 2005 to 2010*, CA: Analytics Press, August 1st 2011, Oakland. Can be downloaded at http://www.mediafire.com/file/zzqna34282frr2f/koomeydatacenterelectuse2011finalversion.pdf

[4] Koomey, J. *Estimating total power consumption by servers in the US and the world,* 2007. Can be downloaded at https://files.me.com/jgkoomey/98ygy0

[5] Fichter, K. *Zukunftsmarkt energieeffiziente Rechenzentren*, 2007, Berlin Borderstep Institut für Innovation und Nachhaltigkeit GmbH. Can be downloaded at http://www.borderstep.de/details.php?menue=22&subid=24&projektid=260&le=de#

[6] Gantz J. and Reinsel D. *The Digital Universe Decade – Are You Ready?* IDC, May 2010. Can be downloaded at http://www.emc.com/collateral/analyst-reports/idc-digital-universe-are-you-ready.pdf

[7] McClure T. *Driving Storage Efficiency in SAN Environments*. Enterprise Strategy Group - White Paper, November 2009. Can be downloaded at http://www.thinksis.com/wp-content/uploads/Driving-Storage-Efficiency-SANs.pdf

[8] Filani, D.; He, J.; Gao, S.; Rajappa, M.; Kumar, A.; Shah, P.; Nagappan, R. *Dynamic Data Center Power Management: Trends, Issues, and Solutions.* Intel Technology Journal, 2008. Can be downloaded at http://download.intel.com/technology/itj/2008/v12i1/6-datacenter/6-Dynamic_Data_Center_Power_Management.pdf

[9] http://www.efficient-datacenter.eu

Acknowledgments

The PrimeEnergyIT project is mainly supported by the European Commission, Executive Agency for Competitiveness and Innovation, EACI.

Balancing Energy Efficiency & Indoor Comfort The Missing Link – Next Generation IEQ LAB

Ashak Nathwani – M. Eng Sc[1]
Lecturer – Mechanical Engineering
University of Sydney - Australia

Abstract

In responding to the challenge of greenhouse emission reductions, intense international attention has turned to energy efficiency in the way we design and operate built environments. However, the risk of compromising Indoor Environmental Quality (IEQ) for building occupants with indiscriminate efficiency measures is high. It is not surprising that there is an intensification of IEQ related research activity; driven mainly by the simple fact that indoor comfort, particularly through air conditioning, typically accounts for more than half of a commercial building's operational energy.

In response to these fundamental drivers, a next generation of *Indoor Environment Quality Laboratory*, with ultimate flexibility, has been constructed at the University of Sydney's Faculty of Architecture, Design and Planning. For the first time, international research community and the broader building sector can examine how multiple IEQ factors combine to affect human comfort, productivity and health outcomes for occupants in built environments.

Heating Ventilation and Air Conditioning (HVAC) Systems play a significant role in achievement of Indoor Comfort and are also major contributors with regards to greenhouse gases – through energy consumption. This paper examines the impact of various types of HVAC systems on comfort vectors, including air distribution and air flow velocities.The types of HVAC systems include:

- Ø Chilled Beams
- Ø Displacement,
- Ø Variable Air Volume – medium temperature
- Ø Variable Air Volume – low temperature.

Discussions and research potential utilising the IEQ Lab facilities of this comparative analysis, involving the above systems with respect to key comfort vectors, are presented.

Keywords: indoor environmental quality, thermal comfort, climate chamber, flexibility, HVAC.

1 **Ashak Nathwani** recently joined the The University of Sydney, Faculty of Architecture, Design and Planning – Australia - as a lecturer in Mechanical Services. He has been involved in the development of different types of air conditioning systems in the two lab chambers and is providing project management of the building services to the University. He recently retired from Norman Disney & Young a leading Consulting Engineering firm, after 33 years. Ashak is also the Chair of Consult Australia's Sustainability Roundtable.

Introduction

Given that the majority of the energy required to operate built environments relates to heating, cooling, ventilating and lighting of indoor environments, it's not surprising that the Intergovernmental Panel on Climate Change focused considerable attention on the building sector in general, and building services in particular, in its Fourth Assessment Report (Levine et al., 2007). Baseline emission between the SRES A1B and B2 scenarios predict that worldwide, buildings will be emitting 11.1 Gt in 2020 and 14.3 Gt in 2030, the most of any sector assessed by IPCC. On a positive note, however, of all the sectors reviewed for greenhouse gas mitigation potential, the buildings sector was identified by IPCC (Levine et al., 2007) as the most promising between now and 2030.

For this significant CO2 abatement potential to be realised, it is imperative that sustainable buildings (both new-build and retrofit projects) meet occupants' expectations for comfortable, productive and healthy indoor environments. Failure to satisfy occupant requirements will entrench resistance to innovative and sustainable buildings in an inherently conservative property development market. Australia has its more than share of award-winning "green buildings," that ultimately disappoint their occupants on the most basic IEQ standards, forcing their owners into costly and often energy-intensive retrofits just to bring them up to minimum levels of occupant acceptability. "Hair shirt" green-buildings can do more damage than good to the green-building movement, and ultimately undermine national policies aiming to ensure Australia makes a fair contribution to the international response necessary to avert dangerous tipping points in the climate system. An IEQ Lab for Australia will for the first time provide a cost-effective tool to alert design professionals to investigate indoor environment problems well before actual building construction begins, instead of waiting for post-occupancy evaluations to discover the mistakes.

The Missing Link – An Indoor Environmental Quality Laboratory for Australia

The principal determinants of occupant overall satisfaction, performance and health within built environments are indoor climate, air quality, acoustical character and lighting. Most white collar workers probably spend 90 to 95% of their day-to-day lives within built environments (Fanger, 1970). The last 100 years have witnessed major international research efforts directed towards quantifying the relationship between the quality of the indoor environment perceived by occupants and the physical character and intensity of the various indoor environmental elements. Considerable effort has also aimed at predicting worker productivity, prevalence of various building-related illnesses and sick building symptoms and absenteeism in response to physical indoor environmental conditions.

The building services principally responsible for creating habitable indoor environments also happen to be the major energy end-uses. Building energy accounts for approximately 20 per cent of Australia's greenhouse gas emissions, split fairly evenly between homes and commercial buildings. Australian, state and territory governments agreed in July 2009 to expand and accelerate energy efficiency efforts through a National Strategy on Energy Efficiency (Department of Climate Change and Energy Efficiency, 2010). During the oil shocks of the 1970s there was a concerted effort to tighten the energy efficiency of buildings. Ill-informed strategies such as reduced fresh-air ventilation rates led to increased indoor air pollution concentrations and unintended along with outbreaks of building-related symptoms, subsequently termed "sick building syndrome" by the World Health Organization in 1984. The thousands of cases of sick buildings reported world-wide since then has led to indoor environmental quality (IEQ) issues being given prominence in the current crop of building sustainability indices (e.g. LEED in USA, BREAM in UK, AccuRate in Australia, the Green Building Council of Australia's Green Star system and the National Australian Building Environmental Rating Scheme). All such sustainability ratings include a significant number of performance points for IEQ-related issues such as comfort, air quality, individual occupant control and adaptive opportunity, low-polluting fit-out materials, etc, which underscores how the resource and IEQ efficiency issues are inseparable in building sustainable environments.

There are two fundamentally different but complementary methodological approaches to indoor environmental research. Field studies are based on large cross-sectional or longitudinal samples of building occupants going about their day-to-day activities in actual office, retail, industrial, educational, residential or vehicle cabin settings. Although field studies provide information that is directly transferrable to the broader population in similar settings, analysis is restricted to statistical descriptions rather than mathematic relationships because exposure conditions cannot be manipulated or controlled. Such statistical analyses require very large samples to ensure coverage the relevant range of environmental parameters, leading to very high field research costs in terms of human, logistical and technical resources.

The second methodology relies on exposure of smaller samples of human subjects to controlled environmental conditions. This approach provides researchers with total control and as such, allows more finely targeted research design than field study. Generalisation from the lab to the real world is possible by ensuring the research conditions faithfully simulate the setting to which the research is directed. By ensuring that the "look and feel" of the simulated indoor environment is as authentic as possible we will ensure that research findings can sustain generalisation to "real" occupants of "real" buildings or vehicle cabins.

While field studies will continue to provide the research team with critical post occupancy feedback in retrospect, the IEQ Lab will enable simulation of alternative scenarios for cost-effective testing for quality. The Indoor Environmental Quality Laboratory (IEQ Lab) will be the first of its kind in which Australia's building research community and the broader building sector can study how multiple factors comprising the indoor environment – including temperature, humidity, air movement, ventilation rates, air quality, day-lighting, artificial lighting, sound and acoustics – combine to affect human comfort, productivity and health in built environments.

IEQ Lab Facilities

The proposed IEQ Lab will provide experientially realistic interior spaces in which samples of human subjects can be exposed to precisely controlled combinations of the key indoor environmental quality parameters. This facility will deliver research outcomes that are directly relevant to Australian designers, building services engineers, property and facilities managers, and the cognate regulatory bodies responsible for Australia's built environments. The IEQ lab's operating capabilities include:

- Simulation of steady-state and transient indoor environmental conditions including thermal comfort, air quality and ventilation rates, lighting and acoustical characteristics;
- Simulation of residential, office, classroom and vehicle cabin settings under various ventilation, air distribution and thermal environmental, lighting and acoustical control strategies and technologies;
- Control of homogenous or complex micro-environments around individual occupants sharing multi-occupant spaces;
- Evaluation of the impact of outdoor or next-door conditions (including temperature, solar and thermal radiation, humidity, wind, day-lighting, noise) on the indoor environment and building occupant comfort, productivity and health.

The facility consists of two purpose-built climate chambers, see Figure 1. Chamber 1 is approximately 60 sq m and Chamber 2, is around 25 sq m, in which all of these indoor environmental parameters can be precisely controlled or transitioned across a broad range of values, in any combination, while a sample of typical building occupants (subjects) go about their typical daily activities for an exposure time (usually a few hours each experiment), all the while registering their subjective impressions (quality ratings) on a comfort questionnaire.

Initially the Lab chambers' fit-out will resemble grade-A commercial office spaces achieving a Noise Criteria of NC 45, but they've been specifically designed for maximum flexibility, so residential, industrial, retail, cinema/theatre, leisure facility, even vehicular (car, bus, train, plane) interiors can also be realistically simulated for modest reconfiguration costs.

Chamber 1 has capability to accommodate 8-12 persons in office type workstation layout in two zones – interior and perimeter. Chamber 2 has the capability to accommodate 4-6 persons in office type workstation layout. It is essentially one zone but has the flexibility to create an interior or a perimeter zone. The perimeter zone of each lab will be adjacent to an "environmental corridor" that will be able to simulate "sun" lighting (using appropriate lamps) and "outdoor" ambient conditions that could create a warm temperate climate, with temperatures of around 40 degrees C, similar to say Darwin in the Northern Territory or cooler climate with temperatures of around 4 degrees C, as found in Hobart, Tasmania. Removable panels over the external windows in the Outdoor Simulation Corridor would permit utilisation of Natural Ventilation and Natural lighting, please refer to Figure 1.

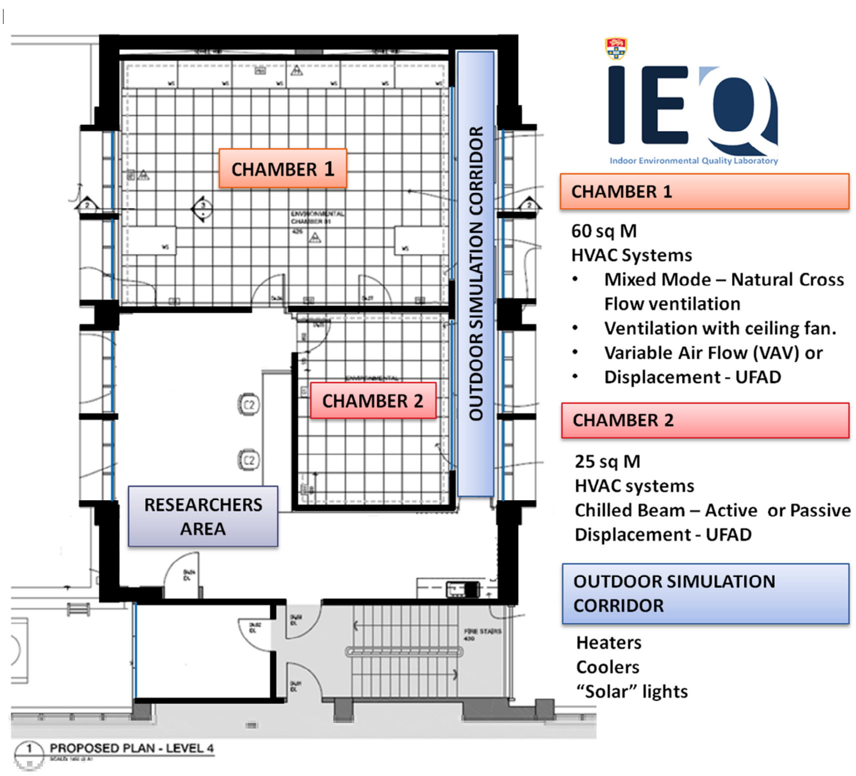


Figure 1. Floor Plan - Indoor Environmental Quality Laboratory.

Building Services

Buildings services have been designed to provide ultimate flexibility to the IEQ Lab, being possible to operate under air conditioning, natural ventilation or mixed-mode regimes, refer Figure 2. In Chamber 1, the air conditioning system is of the Variable Air Volume (VAV) type, with flexibility to incorporate normal as well as low supply air temperature configurations. The basic principle of a VAV system is that the conditioned supply air volume is varied via a motorised damper for each zone to meet the required zone conditions, as dictated by the respective zone thermostat. The air diffusion is through linear diffusers in the ceiling grid.

Return air occurs via slots in the light fittings allowing air to get into the ceiling plenum. The supply air temperature can be set to lower value, in which case the system is referred to as Low Temp VAV system. A heater is incorporated to provide reheat to adjust for the temperature difference between zones. Refer to typical sequence of operation Since the air volume is varied to suit the conditions, the VAV system is very energy efficient. Furthermore, Chamber 1 can be switched over to an Under-Floor Air Distribution (UFAD) system with displacement ventilation. In this UFAD system conditioned air is supplied into the underfloor plenum, in the raised floor, in the appropriate zone. The air is diffused into the zone through swirl type diffusers located at floor level. The UFAD arrangement does not condition the air above the people level and the lighting heat load does not contribute to the overall room cooling load. Hence this type of a system has the potential to offer considerable energy savings. Fan Coil Unit 1 is utilised for the VAV and the UFAD systems, with appropriate motorised change over damper motors. With operable windows on two opposing walls of Chamber 1, there is also the option of natural cross-flow ventilation natural day-lighting.

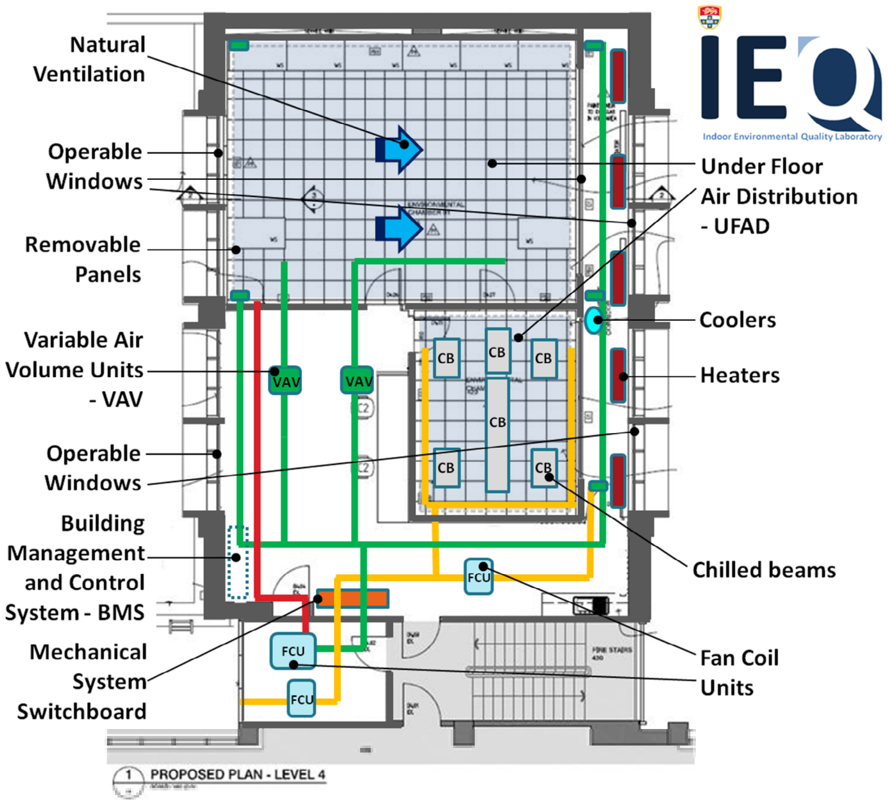


Figure 2. Building services main features – Indoor Environmental Quality Laboratory.

Chamber 2 will have a chilled beam air conditioning system (both active and passive units). These devices use chilled water in exposed coils that produce a cold surface. The cold surface creates a temperature difference and a subsequent convective air current. The higher the temperature differences between the zone and the chilled beam the greater the convective current and hence the air movement. Passive Chilled Beam relies on the convective forces only. Outside or fresh air, to meet code requirements, in this instance would be via the UFAD arrangement. The outside air is conditioned to cater for the latent cooling since the chilled beams only provide sensible cooling. Each active chilled beam, on the other hand, has conditioned outside air connected to it, which through nozzle arrangement creates an inductive air flow over the coil, providing an ability to increase the sensible cooling. Latent cooling is once again via the conditioned outdoor air. Since pumping energy associated with circulation of chilled water is lower than fan power of an equivalent air flow based system, chilled beam system achieve higher operating energy efficiencies. Conditioned Outdoor air is provided by Fan Coil Unit 2.

Figure 3. Active Chilled Beam – Indoor Environmental Quality Laboratory.

Similarly to Chamber 1 there will be the option of UFAD with displacement ventilation for Chamber 2 via Fan Coil Unit 3. There is also a changeover damper arrangement that will have the ability to provide conditioned air to the Researchers Area. The supply of conditioned air to the Researchers shall be through the furniture – with adjustable air outlets. Electric Duct Heaters (EDH) are utilised for provision of heating of the air, where necessary.

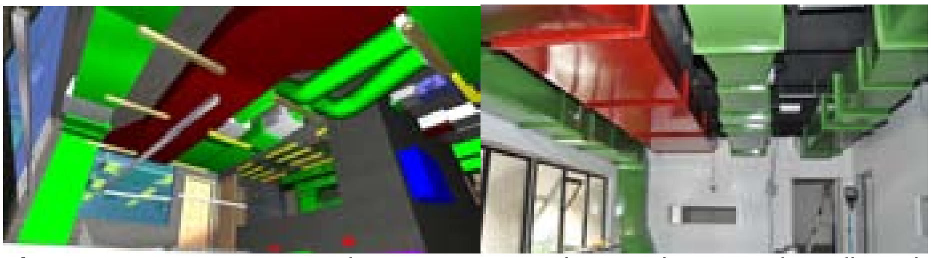


Figure 4. BIM – 3D Vs Actual Duct Layout – Indoor Environmental Quality Laboratory.

Building Management and Control System (BMS)

A state-of-the-art Building Management and Control System (BMS), is employed to program the various indoor and “outdoor” conditions for each research set-up. The BMS will also have the capability to log detailed records of indoor environmental conditions within the occupied zones of the chambers throughout each experimental exposure. Figure 5 shows the schematics distribution of sensors for the entire laboratory. Each zone in Chambers 1 and 2 will have sensors for temperature (at various heights: 0.1, 0.6, 1.1 and 1.7 m), humidity, carbon dioxide and volatile organic compound. There are also temperature sensors in the Environmental Corridor and Researchers area. Each Fan Coil Unit will have supply air temperature and humidity sensors in the supply duct. Each fan Coil Unit also has speed control to vary the volume of supply air

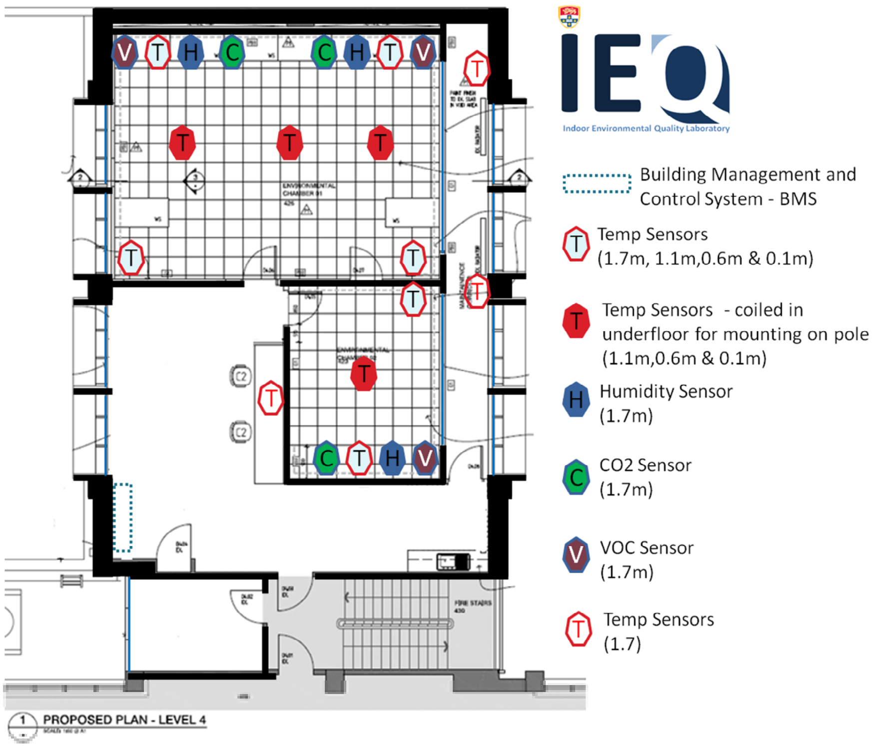


Figure 5. Building Management and Control System (BMS) and sensors – Indoor Environmental Quality Laboratory

Discussions – Comfort Vector Analysis & Energy – HVAC Applications

With the aid of Thermal Modelling, a comparison of energy consumption per year has been carried out of a hypothetical building, utilising:

1. Constant Volume
2. Variable Air Volume or
3. Chilled Beams and / or
4. Under Floor Air Distribution air conditioning systems.

With Constant Volume System as the “Base”, following is established:

Variable Air Volume (with no Fan Assistance) = 0.66 of "Base"
Chilled Beams – Active (Perimeter), Passive (Interior) = 0.52 of "Base"
Underfloor Air Distribution with swirl type diffusers = 0.58 of "Base"

Comparing Comfort Vectors:

System	Temperature	Humidity	Air Distribution	Comments
Variable Air Volume	Good temperature control ability	Low with low supply air temperature	Generally via ceiling with air velocities of 0.2 - 0.3 m/s depending on type of diffusers– can have "dumping effect" at low air flows below 0.1 m/s.There is potential impact on air quality as there is mixing of room and supply air.	Overall – good energy efficiency plus has ability to achieve + / - 0.5 to 0.75 PMV
Chilled Beams	Reasonable temperature control ability. Time lag involved to attain zone temperature during start up – especially in the interior zones with Passive beams	Essential to maintain low dew point to prevent condensation – and hence may experience low humidity.	Air flows subject to heat load in the interior. If fresh air distribution for Passive Beams is via ceiling, then air mixing has a potential impact on air quality.	Overall – very good energy efficiency plus has ability to achieve + / - 0.3 to 0.5 PMV. Flexibility in zoning can be an issue if large size beams are adopted. Due to no "air noise", installation may require introduction of "white noise".
Under Floor Air Distributi on	Very good temperature control ability. Temperature gradient evident between feet and head - which is dependent on air distribution and outlet velocities.	May experience high humidity since supply temperature is high. Hence may require desiccant type of dehumidificatio n	Very good air distribution with an ability to adjust and / or relocate the swirl type diffusers. However air velocities need to be addressed as this has the potential to cause dis-comfort at the feet level. With low level supply, there is less mixing of air and hence the general air quality at breathing level is better than the systems where there is mixing. There is potential for "dust" to be untrained from carpet.	Overall – very good energy efficiency plus has ability to achieve + / - 0.4 to 0.6 PMV

Buildings in Australia are utilising combination of systems. One of the latest "6 Green Star" building has Chilled Beams (passive) on the perimeter and a Variable Air Volume in the interiors. There is a trend to move away from all chilled beam installation – primarily due to operational problems encountered due to knowledge gap between the designers and operators.
There are very few all Under Floor Air Distribution systems in high rise buildings mainly due to higher capital cost and perceived inflexibility in zoning for individual offices.
Variable Air Volume System in buildings built in the 1970s and 1980s still have the ability to achieve good energy ratings of around 4 NABERS Energy Rating (– Range 0 to 6).

Conclusions

As can be seen from the discussions above, that international research is identifying various comfort issues that require further evaluation. The IEQ Lab will for the first time provide a cost-effective tool to alert design professionals to potential indoor environment problems well before actual building construction begins, instead of waiting for post-occupancy evaluations to discover the mistakes. This facility will endeavour to deliver research outcomes that are directly relevant to designers, building services engineers, property and facilities managers, and the cognate regulatory bodies responsible for Australia's built environments. Rather than designing and building environments first, only to discover too late from the occupants that they don't work, this facility will provide Australia's building sector with the capability to identify potential indoor environmental problems at the design stage and eliminate them before construction begins.

This approach will enhance sectorial capacity to deliver innovative and sustainable, low energy built environments that balance Australian occupants' expectations for quality against our obligations to substantively address climate change.

Acknowledgements

Clearly this is an ambitious project and predictably the researchers' aspirations far exceed the financial resources allocated to the IEQ Lab by the university's campus infrastructure services in their 2011 capital works budget. In-kind assistance has therefore been sought from the Australian Heating Ventilation and Air Conditioning (HVAC) industry. The chiller has been provided by Daikin Australia, thanks to the support by John Fraser-Mifsud, national channel manager commercial business. The active and passive chilled beams and displacement diffusers have been donated by Krantz Asia-Pacific – Air Grilles Pty Ltd via Stefan Westenberger's efforts. The BMS system donated by Automated Logic. With tailored programming by Jonathan Clarke of Norman Disney & Young.

Platinum Donation has been received from Coverclub Pty Ltd – Directors - Ashak & Samim Nathwani.

References

1. de Dear, R.J. (2009) "The theory of thermal comfort in naturally ventilated indoor environments: The pleasure principle," International Journal of Ventilation. V.8(3), pp.243-250.
2. de Dear R.J. and Brager, G. (1998) "Developing an adaptive model of thermal comfort and preference", ASHRAE Transactions, V.104(1a), pp.145-167. Reprinted in Schiller Brager, G. (ed.) (1998) Field Studies of Thermal Comfort and Adaptation - ASHRAE Technical Data Bulletin, V.14(1). pp. 27-49.
3. Hodgson, M (2008) "Acoustical evaluation of six 'green' office buildings," J. Green Building 3(4):108-118.
4. Khaleghi, A., K. Bartlett and M. Hodgson (2008) Relationship between Ventilation, Air Quality and Acoustics in 'Green' and 'Brown' Buildings, U. British Columbia, Vancouver BC, Canada.
5. Fanger, P.O. (1970) Thermal Comfort. (Danish Technical Press; Lyngby)
6. Levine, M., D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. 7. Mongameli 6. Mehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino, 2007: *Residential and commercial buildings*. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.ipcc.ch/ipccreports/ar4-wg3.htm
7. Leaman, A., Thomas, L.E., Vandenberg, M. 2007, "Green' buildings: What Australian users are saying', EcoLibrium(R), vol. 6, no. 10, pp. 22-30.
8. Martens, W.L., H. Sakanashi, W. Woszczyk, and S. Olive (2009) *Whole-body vibration associated with low-frequency audio reproduction influences preferred equalization*. In Proc. of Audio Engineering Society 36th Int. Conf., Dearborn, MI, USA (June 2009).
9. Thomas, L.E. 2009, *(Re)developing for Environmental Performance: Learning from the Occupants' Perspective.* In Proceedings of PLEA2009, ed Demers, C; Potvin, A., Les Presses de' l'Universite Laval, Quebec, Canada, pp. 465-471.
10. Zwicker E & H. Fastl (1999) Psychoacoustics: Facts and Models, Springer

Analysis of energy consumptions and complementary measurements in air-conditioned office buildings

Jean Lebrun, Cleide Aparecida Silva and Jules Hannay

JCJ Energetics, Liège, Belgium

Abstract

Building "signatures" correlating fuel consumption with outdoor air temperature may help in understanding the building behavior. But several "perturbations" can make such signatures difficult to read.

Correlations between electricity consumptions and outdoor air temperature are more difficult to establish: only a small part of this consumption is related to the weather. The use of electric steam heaters may even make such correlation negative even if the building is cooled in summer time.

Such global information can be completed by local consumptions recordings, in order to better identify equipment performances. Local measurements are easy to perform on electrical panels, with the help or movable recorders.

Indoor climate recording can also help in identifying actual comfort conditions and also actual performances of terminal units.

A promising analysis consists in using the indoor climate records as input variables in the simulation.

1. Introduction: actual energy consumptions are not well known

No realistic energy saving strategy could be achieved without satisfactory knowledge of past, present and future energy consumptions of the new or existing building considered.

In the design of a *new building*, a fair estimate of the effectiveness of any energy saving option is needed: energy consumptions *with* and *without* such option need to be compared by pure simulation. But, soon or later also, some experimental verification will be badly needed: actual consumptions will have to be recorded and, as much as possible, compared with the previous simulations, in order to assess the design options.

"As much as possible" means here "as far as such comparison is reliable", i.e. providing that all simulation *and* experimental uncertainties are not dissimulating the differences to be identified.

Almost the same sort of verification is required in the audit and in the retrofit of an *existing building:* theoretically, the verification should be easier than with a new building, thanks the information already available about the consumptions *before* retrofit. The dream is then to compare, the *"before"* and *"after"* states, directly, i.e. just through measurements and *without* any simulation.

But such comparison is always difficult, because of too many uncertainty factors and of too many unexpected events affecting the consumptions: the *"after"* and *"before"* (or *"design"*) conditions are never the same and a lot of corrections may have to be applied before getting comparable results.

Correcting the *"after"* state in order to make it directly comparable to the *"before"* or to the *"design"* state is usually not possible without coming back to some simulation…and the simulation itself is not practicable without any satisfactory information about many technical characteristics of the building and of its HVAC system. But older is the building and more difficult it might be to find back such information.

Actual fuel and electricity consumptions are, most of the time, poorly identified and this information is poorly used in the current management of HVAC systems. The consumptions are usually recorded month by month and not on shorter time basis. Moreover, the fuel consumptions are seldom recorded at fixed times and must therefore be corrected before being considered as actual monthly values.

The information presented hereafter is extracted from several IEA and European projects [1 to 6]. Some examples of results extracted from the audit of different buildings are also presented; these buildings are intentionally *not* identified in this paper.

2. Monthly consumptions may help in identifying some building signature(s)

The simplest signature corresponds to the fuel consumption of a building with classical heating system, with fairly stable indoor temperature, almost constant heat transfer coefficient (which, means, among others, fairly constant ventilation flow rate), almost constant internal heat gains (occupancy, lighting, appliances…) and almost constant solar heat gains, or well correlated with the outdoor air temperature.

Such conditions are rather well realized for most residential buildings, but much less for commercial buildings, which are submitted to much more important variations of heat gains and, sometime also, of ventilation flow rates.

Typical examples of heating signatures are shown in **Figures 1, 2 and 3** [7, 8]**.**

The fuel consumptions of these buildings (expressed in average power) are correlated with the average outdoor temperature.

If the indoor temperature was kept almost constant, the *slope* of each regression line of should correspond to the ratio between the global heat transfer coefficient of the building and the global efficiency of the heating system considered.

Any parasitic correlation between the indoor temperature actually maintained in the building and the outdoor temperature can very much affect the slope of the signature: very often, such correlation is positive (the actual indoor temperature tends to increase when the weather is warmer and vice-versa). This may reduce the slope of the signature well below the above-defined ratio [9].

In ideal conditions, the intercept of the signature with the horizontal axis should correspond to the *no-heating* temperature, i.e. the outdoor temperature over which there is no more any heating need. But the use of monthly averages produces a shift of the no-heating point towards higher temperatures, because any month of relatively high average temperature may contains relatively cold periods (a few days or even a few hours) generating some heating demand.

In the three examples presented in **Figures 1 to 3**, the no-heating point is indeed shifted until a temperature of the order of 23°C, i.e. well above the theoretical no-heating temperature (currently around 15 °C or even below).

Another alteration of the signature may be due to the air treatment:

- The pre-heating associated to humidification may generate a strong increase of the slope below a certain outdoor temperature
- And the post-heating associated to de-humidification may also generate a supplement of heating demand above a certain outdoor temperature. This effect is illustrated in **Figure 3**.

A commercial building may contains a lot of very different electrical systems and only a small part of the global electricity consumption is actually depending on the weather. This means that the electrical signature is more difficult to read.

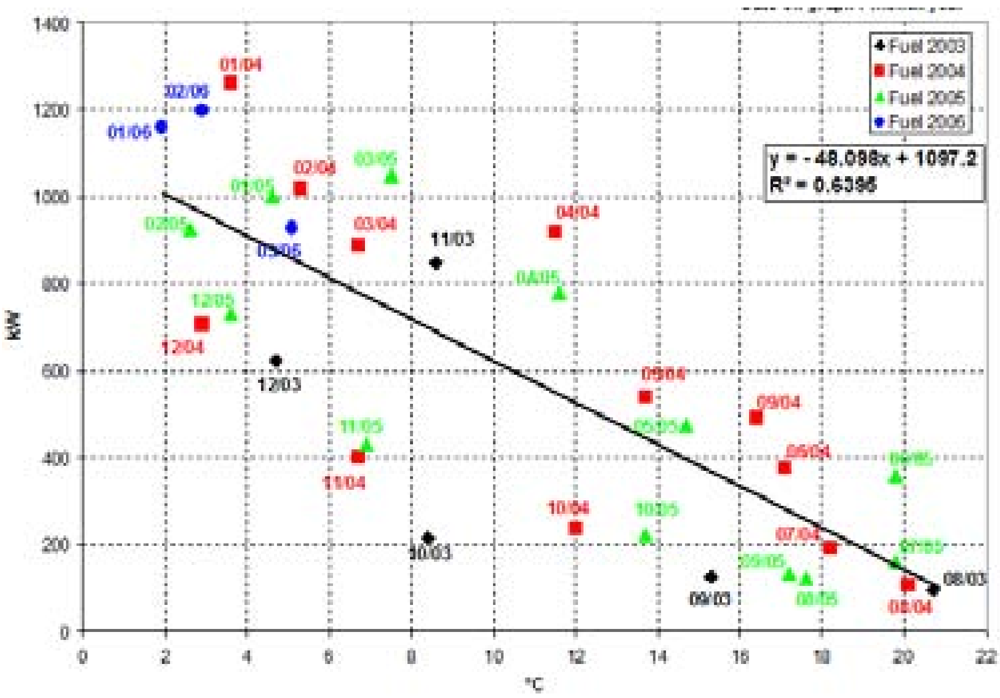


Figure 1: Fuel oil signature of an office building (monthly consumption as function of the average outdoor air temperature)

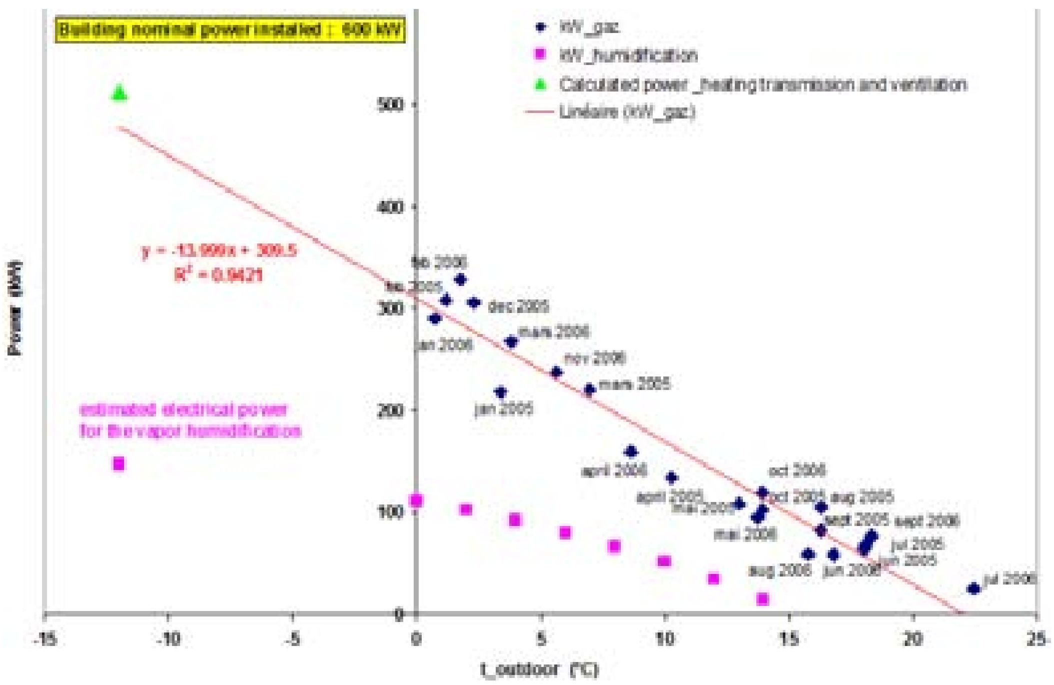


Figure 2: Gas signature of a laboratory building

If this signature is written in monthly averages, the outdoor temperature is strongly depending on the time (the season). This makes, for example, that the lighting consumption might be a decreasing function of the average outdoor temperature, because of the effect of solar radiation (if the building occupants are taking profit of the natural lighting potentials). At the contrary, the cooling demand is expected to be an increasing function of the average outdoor temperature, which explains the positive slope of the electrical signature presented in **Figure 3**.

Electrical steam humidifiers, often used in commercial buildings, can also generate a strong electrical consumption, which is a decreasing function of outdoor average temperature (or of corresponding humidity ratio). Such effect clearly appears in the example of **Figure 4.**

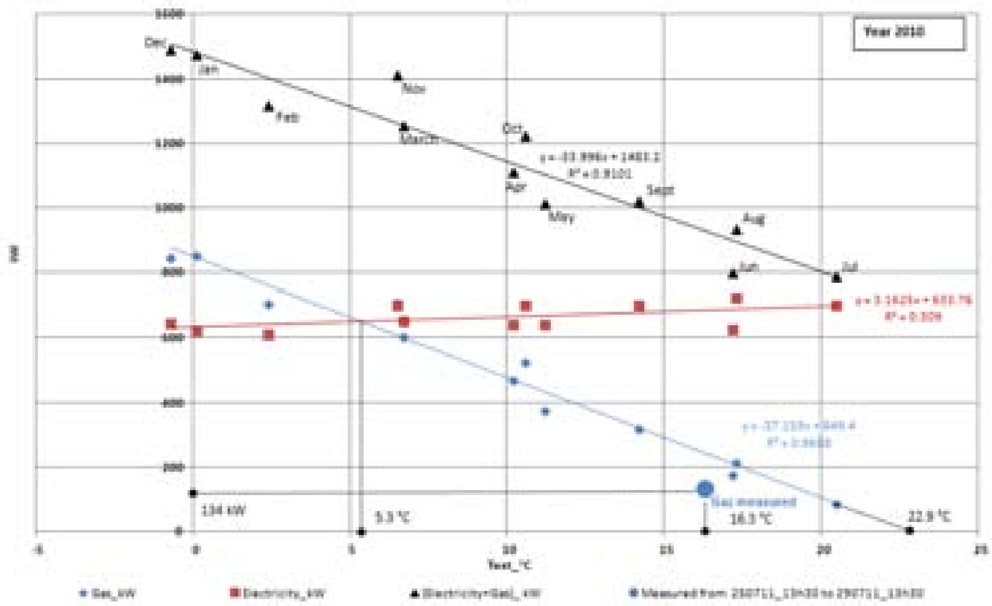


Figure 3: Fuel and electrical signatures of an office building

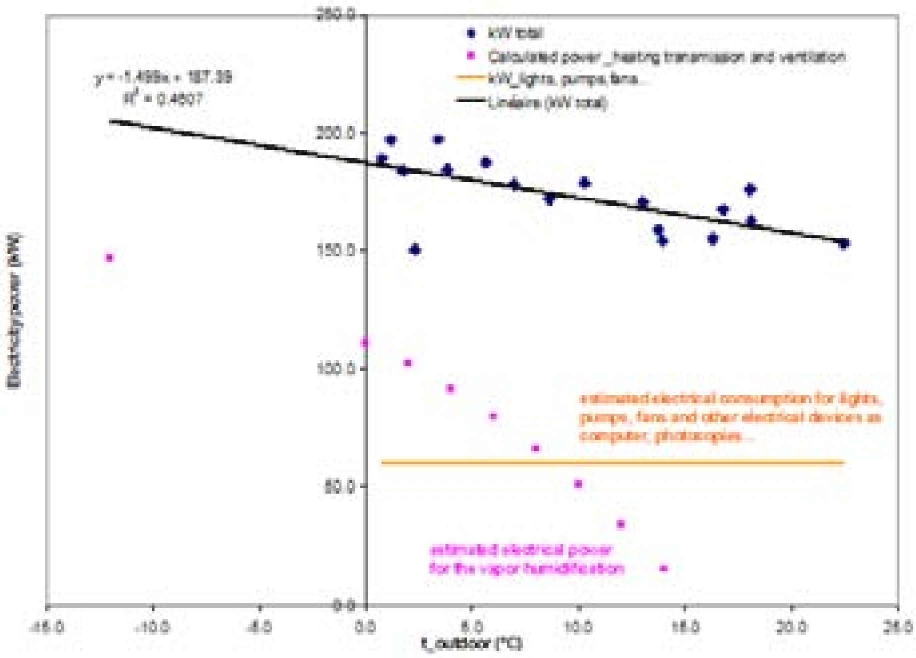


Figure 4: Electrical signature of a laboratory building with electrical humidification

Heat pump heating makes, of course, the electrical signature more significant, as shown in the example of **Figures 5.**

In this case, the effect of highest outdoor temperatures (and of corresponding cooling demands) doesn't significantly affect the signature. This signature is here presented in two ways: from actual consumption recordings and from data generated by simulation [10]. As to be expected, the scattering is a bit larger with experiment than with simulation (which is more deterministic), but this scattering also confirms that, even in monthly average, outdoor air temperature is not at all the only one variable to be considered.

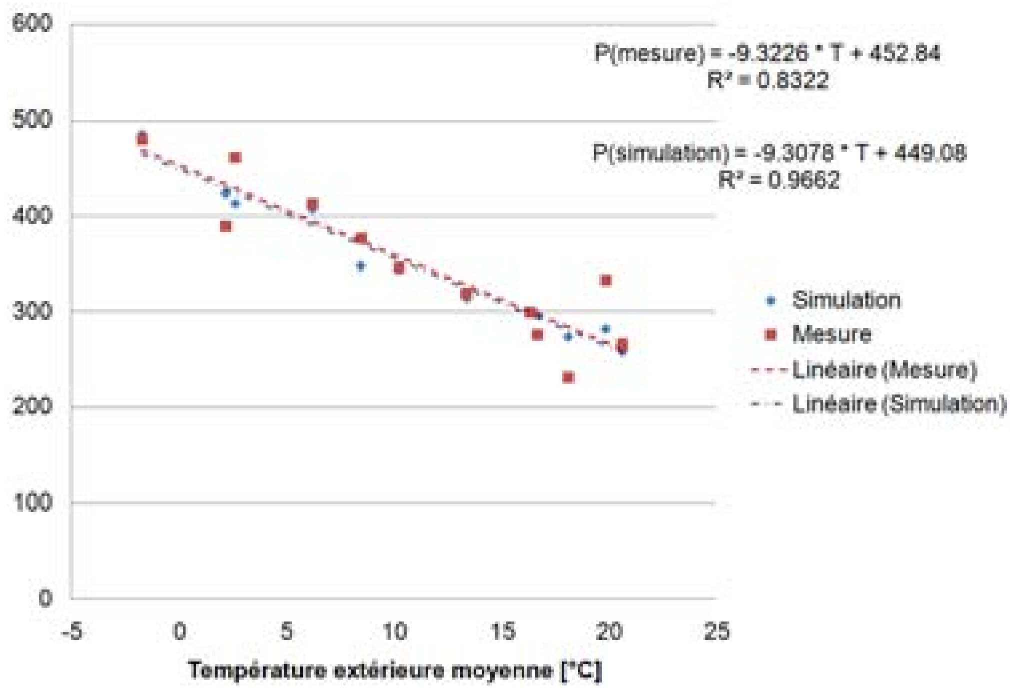


Figure 5: Electrical signature of an office building heated and cooled by reversible heat pump system

3. Daily consumptions should be also considered

If the building energy management system (BEMS) is not doing the job, one could replace it by "hand" recordings of fuels and electricity global consumptions. This is cheap and reliable.

The strong interest of establishing a fuel signature on daily averages comes from the fact that the building time constant is most often of the order of one day. The daily average of the heating demand is therefore strongly related to the daily average of the outdoor temperature.

Electricity suppliers do have records on much shorter time periods (until every 15 minutes in Europe), but their clients are usually not asking for such information.

4. Hourly consumptions may tell a lot

Hourly values of fuels consumptions are usually not available and more difficult to catch. From other part, they are not easy to use, without the help of a very good simulation model and a very detailed knowledge of all other variables (weather, indoor climate, etc.) and of all events occurring inside the building (actual occupancies, activities, etc.).

The hourly heating demand is poorly correlated to the hourly average (i.e. almost instantaneous value) of the outdoor temperature; the signature based on these variables is almost unreadable as shown *by simulation* in **Figure 6** [11].

The same restrictions are applicable to the global electricity consumption of the building: in the example of **Figure 6**, it appears that the cooling demand stays almost constant in the domain of "low" outdoor temperatures; above that limit, the cooling demand can rises with very large scattering.

But hourly electricity consumptions, correlated with time, with weather conditions and with what is known about building occupancy rate, may tell a lot about actual equipments use and about energy saving potentials…

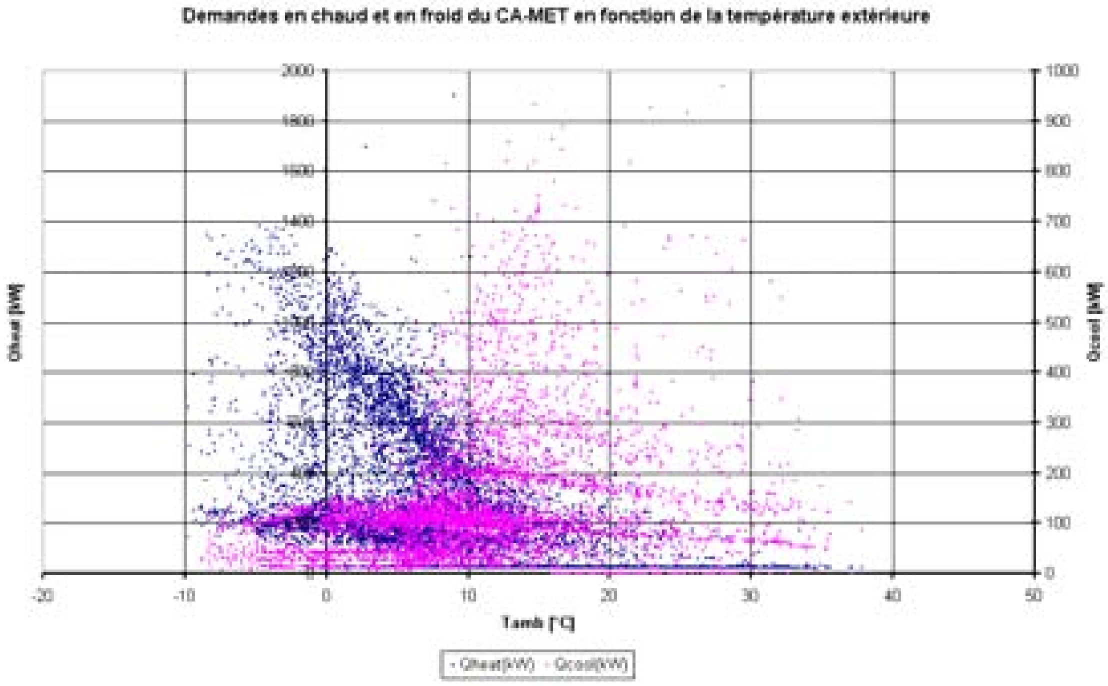


Figure 6: Simulated hourly values of heating and cooling demands of an office building (heating: blue points, left scale; cooling: red points, right scale)

5. Local measurements are also helpful

The information currently available about *global* consumptions can be completed by *local* recordings, in order to better identify equipment performances. Local measurements are easy to perform on electrical panels, with the help of movable recorders.

An example of such recording is presented in **Figure 7.** It corresponds to one half - storey of an office building. A simple analysis of this recording reveals significant differences among theoretical and actual occupancy schedules: late arrivals, strong afternoon occupancy peak and late departures. For private life and safety reasons, direct recording of actual occupancy is not permitted, but night consumption is significant and hardly justified; different wastes can be suspected: useless lighting, computers in standby, etc.

In **Figure 8** is presented an example of recording performed on the electrical panel of a chiller of the same building. The day and night averages are of the order of 28 and 5 kW, respectively. The unjustified night consumption seems to be due to a control problem. But the morning peak is well justifed by the cooling-down of the whole chilled water distribution circuit. Hopefully in the case considered, this peak is occuring early enough for not affecting the *global* peak and the corresponding cost of electricity...

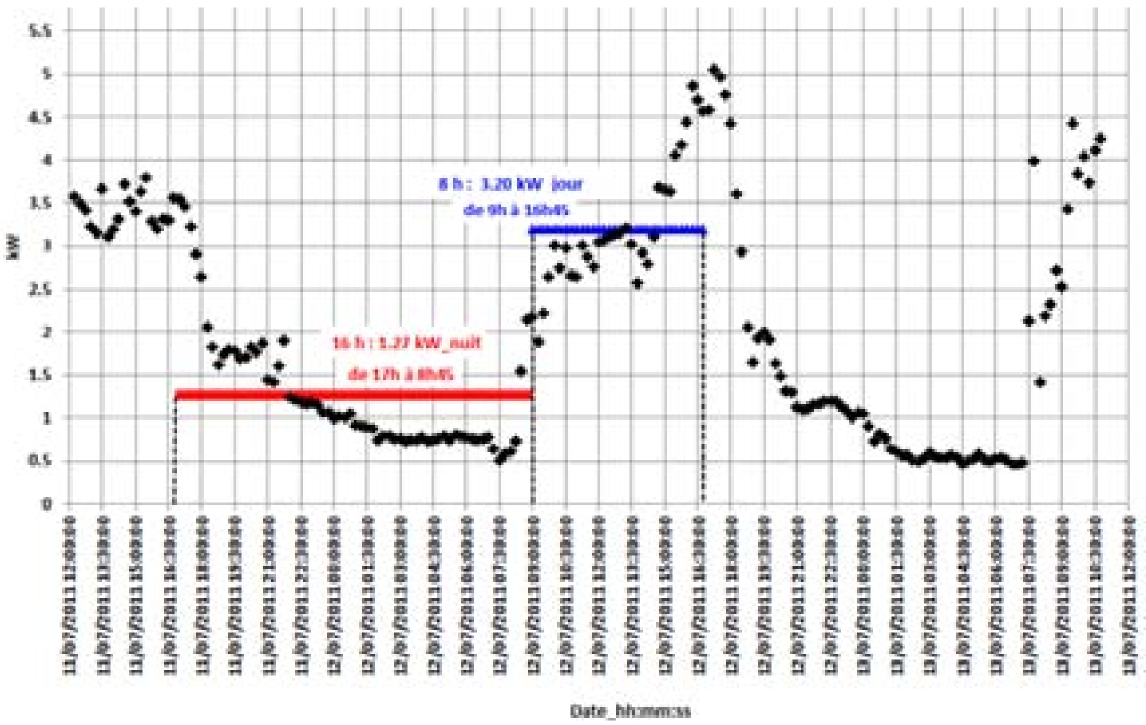


Figure 7: Electrical consumptions of a part of an office building in mid season (lighting, fans, pumps and appliances)

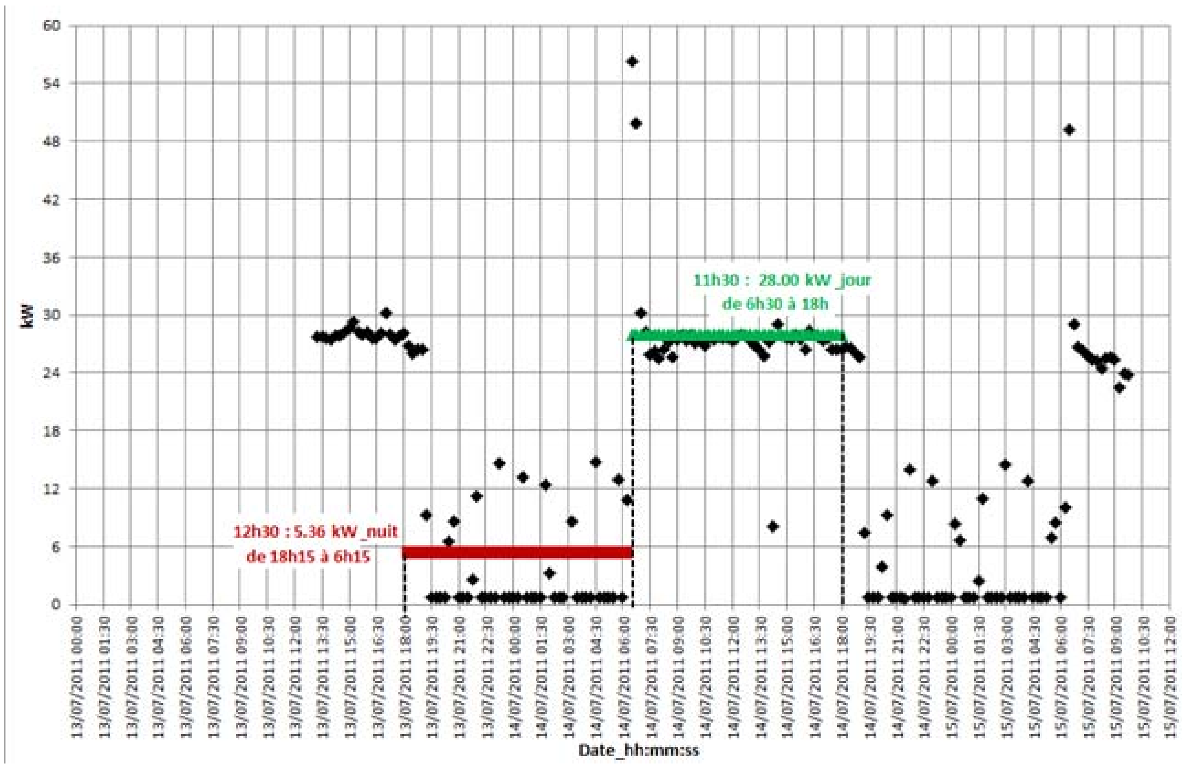


Figure 8: Electrical consumption of one chiller of an office building in mid-season

6. Indoor climate also disserves to be recorded

Indoor climate recordings may also help in the analysis of the energy consumptions.

The very first information source should be the BEMS, if well used. But this information can be completed with the help of movable sensors, distributed among the different building zones and movable recorders.

Cheap and reliable sensors are already available for local recording of temperature, relative humidity and (“equivalent” or actual) CO_2 concentration.

This means it’s becoming possible to record the indoor climate in many (if not all) the building zones. Such approach may help a lot in detecting control failures and/or energy saving opportunities:

- *CO_2 concentration* is usually accepted as a fairly reliable criterion of indoor air quality; from its knowledge, it’s possible to estimate the fresh air flow rate for a given occupancy (and activity) rate or vice-versa.
- *Air and/or globe temperatures* can be used to estimate the thermal comfort conditions in the zone considered.
- The *air humidity ratio* is not only an environmental variable to be maintained in an acceptable range. With some care and as rough approximation, it might also be used as a substitute to CO_2 to estimate fresh air flow or occupancy rates.

By comparing the air temperature measured at different point inside a zone, it’s also possible to get a fair estimate of the air diffusion effectiveness. This one can be significantly reduced because of short circuit effects, as illustrated in **Figure 9**.

Such “short circuits” reduce the thermal power produced by a terminal unit for a given difference between the indoor temperature and the temperature of the fluid (water or air) supplied to the terminal unit) and vice versa.

The air diffusion effectiveness (epsilon) can be defined as follows:

$$\varepsilon = \frac{t_{su} - t_{ex}}{t_{in} - t_{ex}}$$

With

tsu=air temperature at fan coil supply

tex=air temperature at fan coil exhaust

tin=air temperature at occupancy zone center

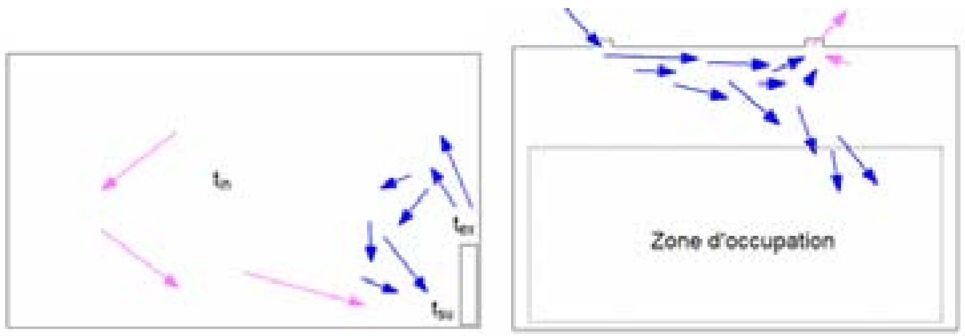


Figure 9: Possible short circuit effect at the level of a terminal unit

An example of "short circuit" occurrence with fan coil cooling can be observed in the example of **Figure 10**:

- The room air temperature (black squares) is (more or less well) maintained around 24 °C during the day and freely floatting during the night;
- The fancoil exhaust air temperature (blue triangles) is going down until 12 °C in early morning (when there is probably a peak of cooling demand) and rising later, until reaching the room temperature, at end of the day and during night (when the chilled water valve is supposed to be closed);
- The fan coil supply air temperature (red circles) is, in some way, "following" the exhaust temperature.

During occupancy time of the second day, the following temperatures are recorded:

t_{su} = 18 [C]

t_{ex} = 13 [C]

t_{in} = 23 [C]

which gives

ε = 0.5 [-]

Correcting this default (by increasing the fan speed and/or by re-orientating the air jet at fancoil exhaust) would open the possibility of rising very significantly the chilled water temperature and, therefore also, the COP of the cooling system.

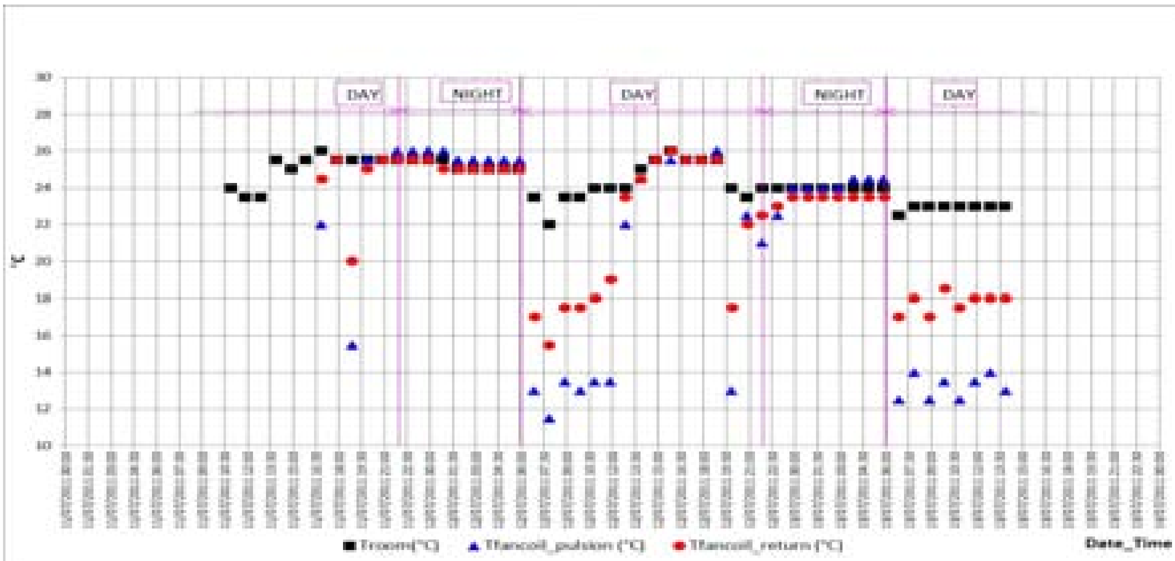


Figure 10: Example of air temperatures records in an office room with fan coil cooling

An example of temperature and humidity recording performed in a data center is presented in **Figure 13**. This recording makes appear a control problem: the air temperature is maintained between 20 and 22 °C (which is already below the typical requirement for a data center) during the first days and falls until 15 °C on the last two days! Correcting such problem and re-tuning the set point might improve a lot the EER of the cooling system.

The increase of relative humidity observed on the two last days of the same diagram is just a “reflect” of the lowering of dry bulb temperature: the dew point stays here almost unchanged…

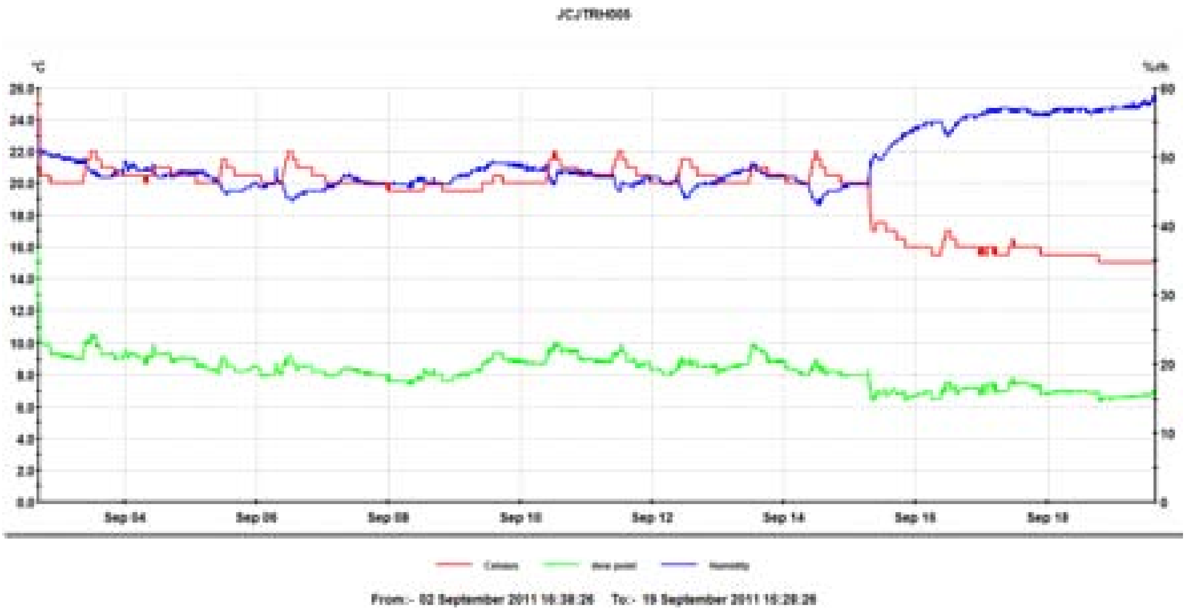


Figure 13: Temperatures (red), relative humidity (blue) and dew points recorded in the data center

7. A promising method

A promising method of analysis consists in simulating the building with all measured indoor temperatures, humidity’s and CO2 concentrations as input data and in comparing the simulated and recorded energy consumptions.

It’s indeed much easier to record these environmental variables than to measure the actual sensible heat, moisture and fresh air flow rates actually provided to each building zone.

This is the contrary to what is done, until now, in most simulations: some control laws and set points are imposed, in such a way to reproduce as well as possible (but with questionable accuracy) the real behavior of the (building and HVAC) system.

In the new approach considered, one would be sure that the indoor climate is fully realistic, because being imposed *as recorded* and focus could be given on the most important result: the energy consumption.

The new approach, which is, at present time, being tested on the simplest case of a dwelling [5, 12, 13], appears as very expedient: calculated and measured consumptions can be directly correlated to each other, to assess the simulation accuracy and also to tune the simulation model when required.

Examples or results obtained on one month are presented in **Figures 14 to 16**.

The temperatures recorded inside four building zones, associated to the outdoor temperature are plotted in **Figure 14**; the corresponding simulated dwelling global heating demand is plotted in **Figure 15** and its integration as function of the actual electrical consumption is plotted in **Figure 16**.

Simulations are here performed with a multi-zone lumped model in which all the internal and external walls are represented by first order R-C-R schemas.

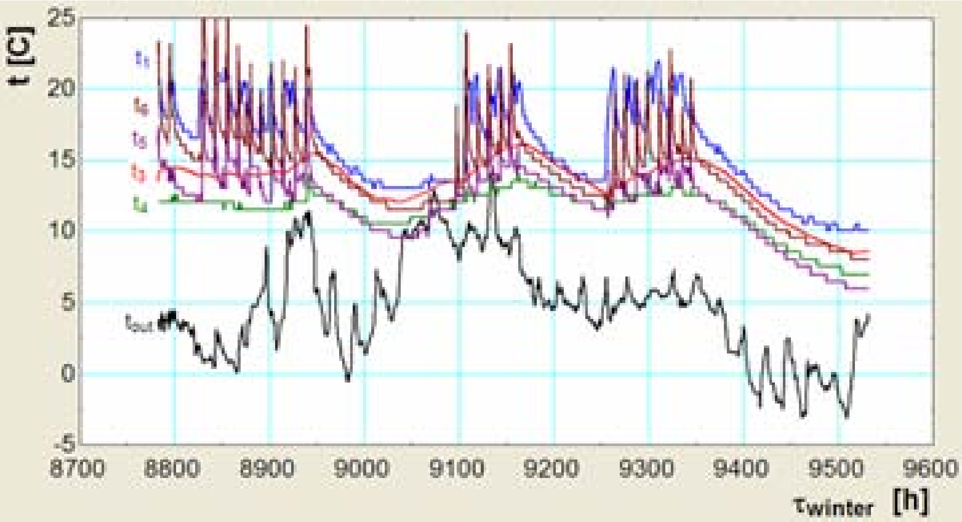


Figure 14: Indoor temperatures recorded in four dwelling zones (in colors) and corresponding outdoor temperature (in black) on one month

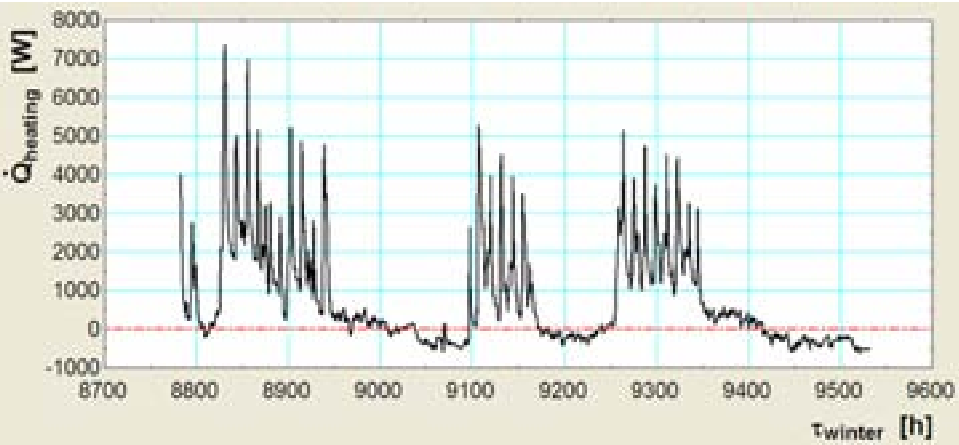


Figure 15: Simulated global heating demand corresponding to the temperatures of Figure 14

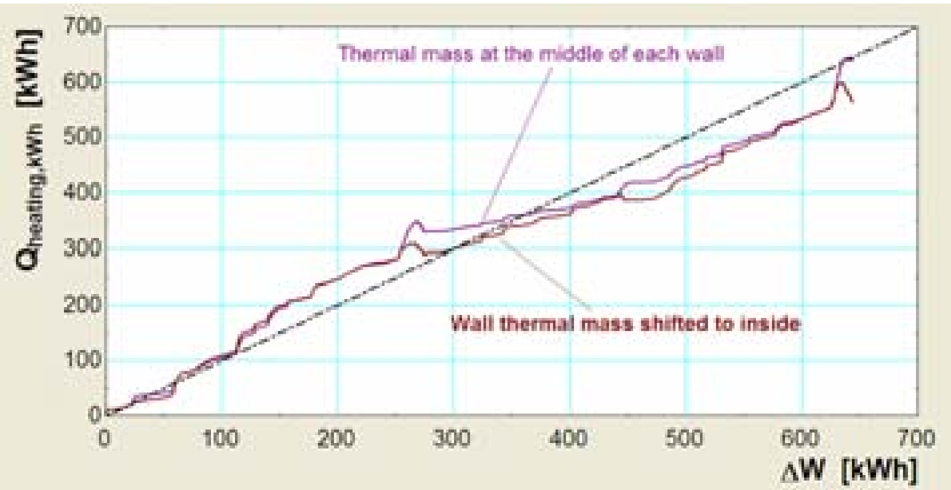


Figure 16: Simulated heating demand plotted as function of the actual electrical consumption (both integrated)

Such correlation analysis will probably be of great help in the management of HVAC systems and in the development of smart metering methods.

8. Conclusions

Correlations between monthly fuel consumptions and main outdoor temperatures can be used as building heating signatures.
Such signatures may help in identifying some management weakness.
Electrical signatures, established in same way, are not always easy to read, but they also can help in identifying some possible waste.
Recordings performed on shorter time base can tell more about the actual energy management.
Information given by the existing building energy management system can be completed with local measurements performed with the help of movable recording systems in order to track the consumptions in different parts of the building and of its HVAC system.
Thanks to indoor climate local measurements, it's also possible to check the actual performances of HVAC terminal units and, among others, to indentify the control and air diffusion effectiveness's.
A promising method might consist in using all indoor climate records as input data in the building simulation in such a way to allow a direct comparison between simulated and actual consumption…

9. References

[1] IEA-ECBCS Annex 11: *Energy Auditing* (1985-1988)

[2] IEA ECBCS Annex 40: *Commissioning of HVAC systems* (2000-2005)

[3] IEA ECBCS Annex 43: *Validation of simulation models* (2003-2007)

[4] IEA ECBCS Annex 48: *Heat pumping and reversible air conditioning* (2005-2009)

[5] [IEA ECBCS Annex 53: *Total Energy Use in Buildings - Analysis and evaluation methods* (2009-2012)

[6] AUDITAC European Program: *Audit of air conditioning systems* (2005-2006)

[7] André Ph., Hannay Cl., Hannay J., Lebrun J. *Example of audit of an air conditioning system.* Klimaforum Godovic, Slovenia, 28 September 2006

[8] Aparecida Silva Cl., Bertagnolio St. et al. *Heat pumping and reversible air conditioning; retrofit opportunities in a laboratory building.* ISHVAC 07, Bejing, China, September 2007

[9] A. Boyens, M. Cornet, J. P. Eppe, J. Lebrun and G. Masy: “Audit and Monitoring of a Large Residential Building in Liege” ICBEM 87, Lausanne 1987.

[10] Bertagnolio St., Andre Ph., Lemort V. *Simulation of a building and its HVAC system with an equation solver: Application to audit.* Building Simulation 2010, 3, 139 -152.

[11] Adam Chr., André Ph., Lacôte P. et al. *Vérification des performances d'un immeuble de bureaux.* Research report, Liège, November 2002.

[12] Aparecida Silva, Cl., Hannay, J. and Lebrun, J. *Thermal simulation and monitoring of a dwelling.* ISHVAC 2011, Shanguai, November 2011

[13] Aparecida Silva, Cl., Hannay, J. and Lebrun, J*. Thermal Simulation and Monitoring of a Dwelling (Continued)*. IEA-ECBCS working document, August 2011

Energy efficient Refurbishment of Induction Systems

Ralf Wagner

Wolf Hartmann

Abstract

In the decade between 1965 and 1975, a large number of office buildings were air-conditioned by induction systems. The terminal induction units have been installed below the windows to ventilate the perimeter areas of open landscape offices. They were helpful to compensate the discomfort by insufficient insulation and tightness of facades with larger glass areas and low solar shading.

Today many of these air-conditioning plants are still in operation and in an acceptable technical condition. The reason for the long lifetime of induction units is the simple, flexible and robust technology.

The paper presents the third generation of induction systems and perimeter units, qualified for refurbishment and new office buildings. The main features are demand controlled ventilation by primary air, low primary pressure and a new air diffusing system for higher comfort und lower energy.

Induction technology in the past

Induction systems have been the first air-and-water-systems in office buildings. The reason for the great success was the relative high cooling and heating capacity of the induction units, which are by a factor 2 - 3 higher compared with an only-air-system at the same air volume rate. For a cooling load of 100 W/m², an hourly primary air exchange of 3 - 5 1/h was necessary. A typical design of an induction unit of the second generation for a unit with 1m width was (see Fig. 1):

- Primary air volume rate, constant — V_p = 100m³/h
- specific outdoor air rate — v_p = 9m³/(h m²)
- primary pressure — • p_p = 300 Pa
- secondary cooling capacity — Q_{sec} = 800W
- specific maximal cooling load — q_c = 110 W/m²

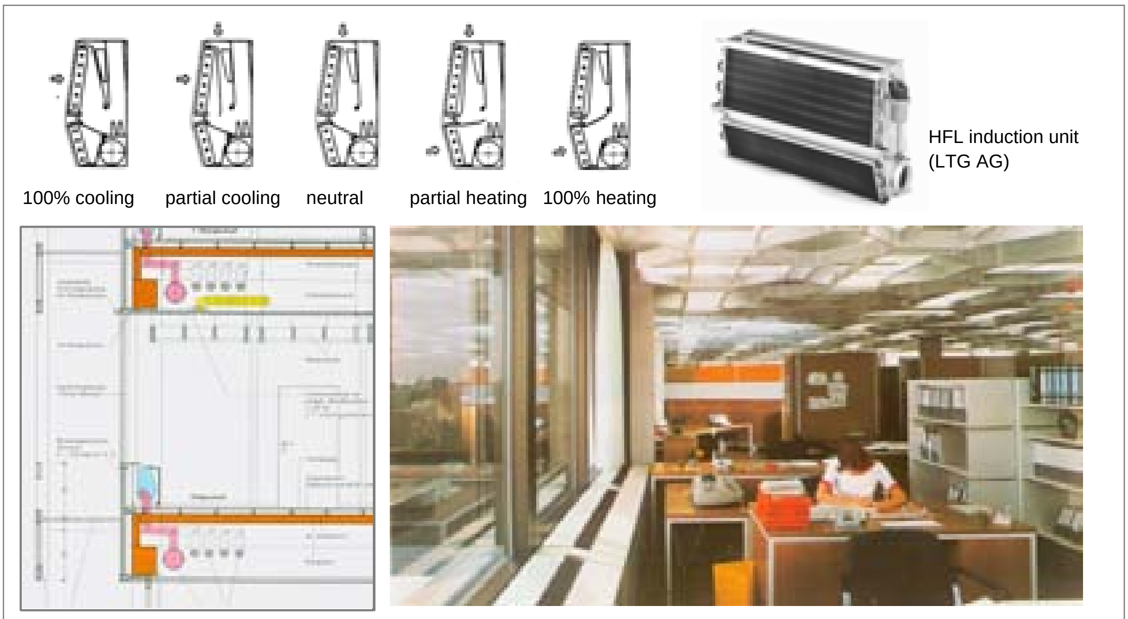


Fig. 1: Cross section of an induction unit with damper control and example of installation

Damper and actuators, driven by compressed air, control the waterside capacity. The heating and cooling coils are connected to a 4-pipe water system. The velocities in the primary air ducts are in the range of 10- 15m/s for vertical distribution, 6 – 8m/s for horizontal distribution and 3- 4m/s at the inlet of the spigot. In consequence of the relative high velocities, the supply fan has to overcome a pressure drop of 1000 - 1500Pa, with an electrical demand for air transport of 1600 – 3000 W/(m³/s) in accordance with SFP-class 4 – 5.

Masuch and Steinbach [1] calculated 1976 an optimal yearly energy demand of an induction system with 75% heat recovery, 3 ACH in parts of end energy per m² air-conditioned area as

- Primary and secondary heat — 65 kWh/m² (without heat in AHU-shut-off mode)
- AHU and secondary cooling energy — 37 kWh/m²
- electric energy for fans — 27 kWh/m²

The sum of these parts, converted to primary energy demand, is 223 kWh/m²/a, a very ambitious value, compared to 520 KWh/m²/a published by Hönmann [2] as a typical mean value for air-conditioning in 1973.

Today in Germany, still some thousands of induction systems are in operation. In many plants control systems have been replaced by an electronic room temperature controller. Operators reduced primary air rates to spare energy and decrease the noise level by the nozzles of the induction units. However, many occupants are dissatisfied with thermal comfort. The tangential flow of an induction unit of the first and second product generation generates a strong vortex flow to ventilate a perimeter area up to 6m of the room depth. The result are velocities above 0,2m/s and a draft rating according to ISO 7730 [3] class B or C with 20 to 30% of persons, complaining about draft. 18 years ago, LTG Aktiengesellschaft developed a new ventilation principle, a combination of mixing and displacement flow, the so-called “Misch-Quell-Lüftung”, which was adopted by VDI 3804 [4]. Figure 2 shows the principle: The supply air jet in the discharge of the terminal is divided by a system of guiding vanes in diverging single jets with high induction and mixing energy. By this, the penetration of the supply air jet is limited to a vertical distance of 1 – 2m. In cooling mode, the supply air sinks to the floor and diffuses as displacement flow. In the past, most of new and refurbished induction terminals have been equipped with guiding vanes.

Fig. 2: Smoke visualization of mixing and displacement flow

Refurbishment of induction systems

In the application of an “Energiepass” in Germany, the energy demand for heating, cooling and ventilation of a refurbished building is compared with a “new” reference building with the same office area and use (DIN V 18599 [5]), but with a standard air-conditioning (fan coils). The demand of the refurbished building must be below 140% of the demand of the reference building. What is to consider, modernizing induction units for energetic aspects?

1. Design hvac-capacities for lower heat and cooling loads (minimal standards for lagging and solar protection referred to EnEV 2009)
2. Decrease primary air rates to hygienic minimum rates (e.g. [6] low polluted building, class II: 5m³/h/m² and [5] Part 10). The initial SFP will drop from i.e. 2000 to 800 W/(m³/s) when primary air rate is reduced from 9 to 5m³/(h m²) and supply duct system is the same.
3. Reduce air volume rates by demand controlled ventilation [DIN V 18599-7]
   $V_{DCV} = (V_{Build} + (V_{Build+Persons} - V_{Build}) F_{RLT}) (1- C_{RLT}) + V_{Build} C_{RLT}$
   with coefficient of operation time F_{RLT} and relative absence C_{RLT}.
   Compared with a CAV-System, which is a standard for induction systems, the mean air rate

for DCV-ventilation of an open plan office is 8%, of a single- and team-office 26% and of a conference room is 63% smaller.

4. Lower primary pressure, e.g. 100Pa (EnEV-reference for supply fan is 1.500W/(m³/s)).
5. High cooling water temperature (16-18°C) and low heating water temperature (30- 40°C) enable higher COPs of heat pump/ chiller and a better recovery of environmental energy.

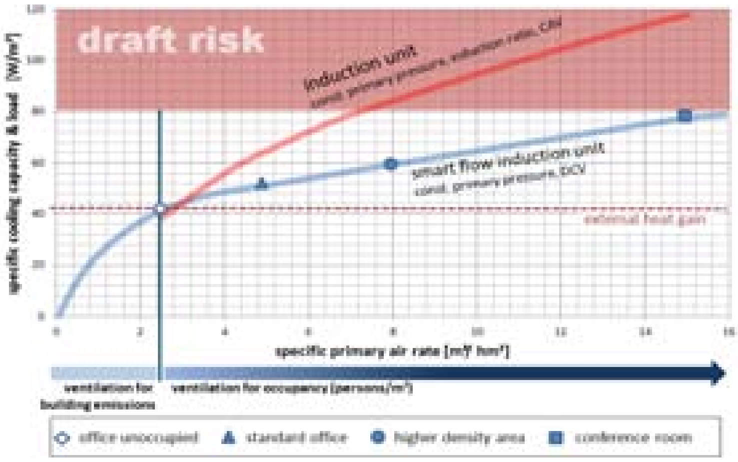


Fig. 3: Cooling load and capacity dependent on occupancy

Thermal comfort and cooling loads by office activity and density of occupancy (persons per m²) mainly determine the design of the induction units. The cooling load for a constant external load of 42W/m² for a room depth of 5m is displayed in fig. 3 as a function of the specific primary air rate in m³/(h m²). The minimal specific air rate (100% outdoor air) is dependent on the density of occupancy (Persons/m²) and outdoor air rate per person (25m³/(h person)) in accordance with DIN EN 15251 [5]. The variable part of the heat gains is calculated with the density of occupancy and the heat gains of office equipment. The blue line connects four typical cooling and ventilation loads in a building: an unoccupied room, a standard office, an office with workstations and a crowded conference room. 2,5m³/(h m²) are the minimal ventilation rate for each unoccupied type of room. The red curve shows the cooling capacity of an induction terminal which is designed for a fixed primary air rate (CAV). For higher occupancy and primary air rates, the cooling capacity is higher than the heat gains in the room. The valve throttles the waterside capacity, but secondary air exchange is still high. The red area represents the region of draft risk with more than 20%-dissatisfied occupants. Most induction units are designed close to this region. For conference rooms it is state of the art, to oversize induction units, accept a higher level of air velocities, and switch off a part of the terminal units, when the room is not occupied.

The "ideal" induction unit follows the cooling- ventilation capacity curve:

- Primary air volume rate, variable — V_p = 10 - 120m³/h
- specific outdoor air rate — v_p = 2 - 15m³/(hm²)
- primary pressure — • p_p = 100 Pa
- cooling capacity (water inlet 16°C) — $Q_{sec,c}$ = 200 - 800W
- specific maximal cooling load — q_c = 40 - 80 W/m²

The heating capacity at low water inlet temperatures (i.e.40°C) varies from 100W static, without ventilation up to 400W at 4m³/h/m² for reheating.

The following steps are necessary for an energy efficient retrofitting of induction systems

1. If not yet existing, install heat recovery system.
2. Pressure control in main supply and extract ducts by fans with variable frequency drives.
3. Control of primary pressure in horizontal duct branches for definite office areas up to 400m² (see fig.4).
4. Pressure controller measures airflow rate for definite office area and transfers actual value as set point to exhaust volume controller.
5. Install transfer- air diffusers in single office rooms for local extract air

The control on duct pressure and air balance is the first step, when the refurbishment is started in a running building. This allows operating old and new terminals at different primary pressures and air volume rates. Larger inner zones with a separate low-pressure ventilation system should also be retrofitted by a DCV-system. CO_2-sensors in the extract duct shift the set points of the volume controllers in the supply and extract ducts.

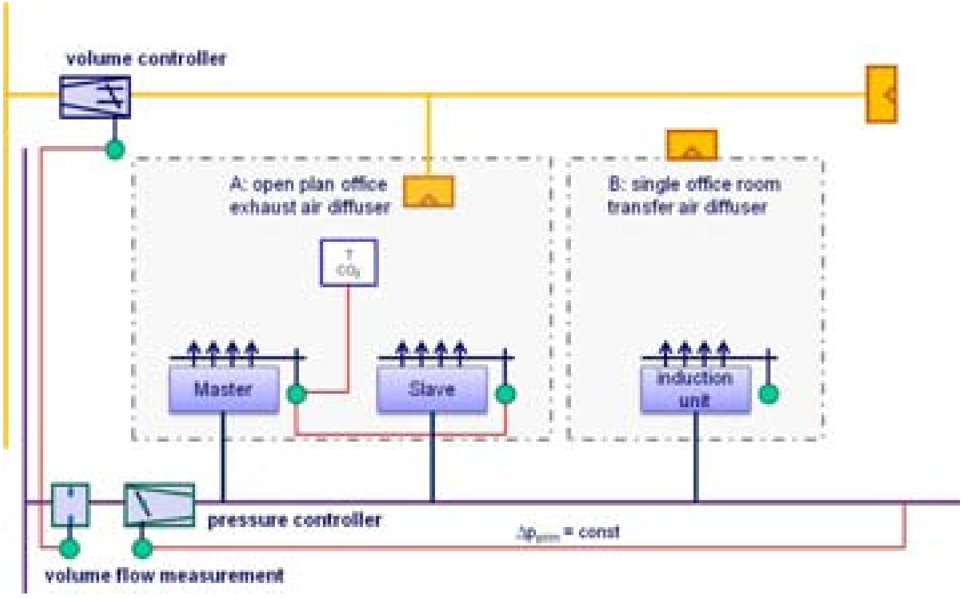


Fig. 4: Control of supply and extract air rates of a DCV-System

Induction terminals for demand controlled ventilation

The new room terminals of third generation can match all loads at a minimum air volume rate, as shown in fig.3. The primary air can be varied continuously and linear to the control signal from cut off to maximum at a low sound power level < 35 dB(A). Thermal comfort meets class B (ISO 7730) in every point of operation.

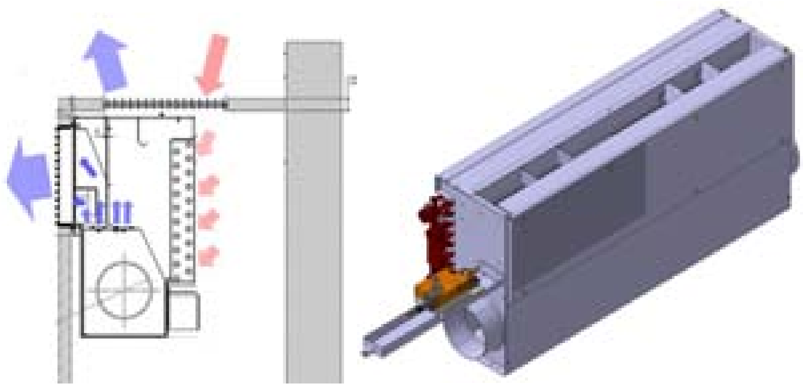


Fig.5 : DCV- induction unit (LTG AG) with two diffusers for mixing and displacement flow

Fig. 5 shows a section of an induction unit and the integration within a cabinet below the window. Secondary air from the room, close to the façade, enters grille, passes heat exchanger and is induced by primary nozzle flow. A mixture of primary and secondary air (1:5), chilled or cooled by the heat exchanger, is vertically diffused in the room. Guiding vanes in the discharge divide the supply flow in several highly inductive single jets. This mixing flow field is locally limited to an area of maximal 1m distance to the façade surface (see smoke visualization in fig. 2). The mixing flow collapses to the floor and spreads horizontally as displacement flow. The supply temperature is close below the mean room air temperature. This ventilation type is called “Misch-Quell-Lüftung”, a combination of local mixing flow and displacement flow within the occupancy zone of the room, up to 6-8m in the room´s depth.

As this flow type is limited by thermal comfort, as shown in fig.3, the primary air rate is increased by opening the nozzle area of a second air diffuser. This diffuser creates a low momentum displacement flow. The superposition of both flow fields allows higher air rates, up to 120m³/h at low velocities, as seen in the flow visualization in fig.6 and in fig. 7, where mean velocities are illustrated by color plot.

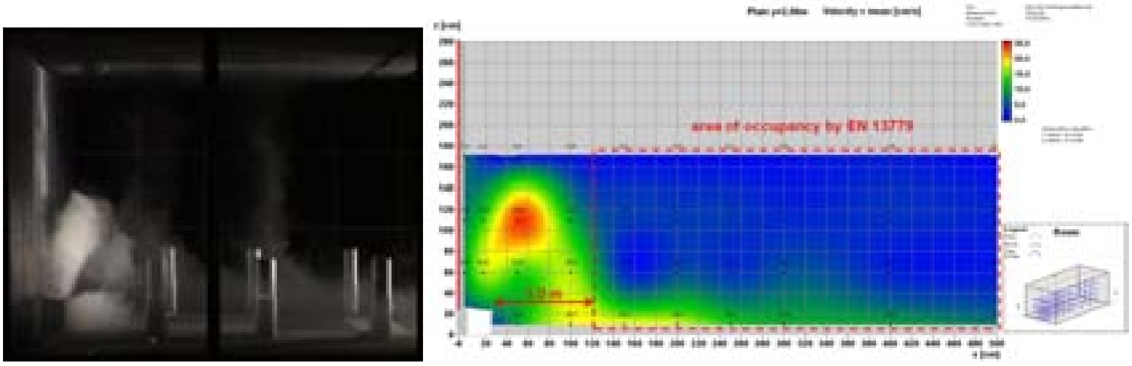


Fig. 6, 7: Superposition of mixing-displacement and pure displacement flow

The following modes of operation can be realized with the same type of induction terminal in an air-conditioning system with highly different loads and room types [7]:

1. CAV-mode (constant air volume) with mechanically fixed nozzle area for rooms with low occupancy and loads
2. DCV-mode in 2-steps of airflow, controlled by occupancy sensors. The infrared sensors can also be connected to the lighting. This control is an economic solution for single rooms for 1 – 3 persons or for workstations in larger office areas in combination with local temperature control
3. DCV-mode with stepless variation of primary air rate by air quality sensors, especially by maintenance-free infrared absorption CO_2-sensors. This control is recommended for open plan offices and conference rooms.

Air quality sensors are tried and tested for hybrid ventilation. In the mode of natural ventilation, the air quality controller can be programmed, to switch off the mechanical supply air. The user can influence his indoor climate in a high degree of freedom, in contrast to induction systems in the past. He decides for natural or mechanical ventilation, he influences air rate and room temperature according to his thermal comfort. Induction systems of third generation adapt their flow field to thermal loads and variable primary air rate to achieve maximum thermal comfort and best indoor air quality at lowest energy demand.

Energy demand of energy efficient induction system retrofitting

The new induction terminals allow retrofitting without changing the induction system. In this case, the air-conditioning can be retrofitted in sections, while the rest of the building is in operation. Ducts and pipes can be further used. Most of the AHUs are qualified for refurbishment. In Germany, the local fire department has to approve all measures concerning ventilation and fire protection.

Table 1 shows three alternatives of refurbishment and parameters for energetic aspects. Central energy demands for heat and electricity are distributed to the terminals, dependent on their air volume rates. The mean primary air rate is a mix of room types in the office building with following distribution, for example: 60% single offices with 5/ 3,7m³/h/m², 25% open plan offices with 4,2/ 3,8m³/h/m² and 15% conference rooms with 15/ 5,6m³/h/m². The first digit is the minimum air rate for CAV, the second for DCV. The mean values for the whole building are 6,3m³/h/m² for CAV and 4,0m³/h/m² for DCV. One induction terminal ventilates 8m² of office floor space.

The first version of retrofitting (V1) describes the installation of a central heat recovery for the AHUs and new induction terminals of third generation, with manually fixed volume rates in CAV-mode. The outdoor air rates are designed for a minimal hygienic standard. The largest benefit is the saving of ventilation heat loss, because the original AHU, version 0, has a heat recovery by 20% recirculation of exhaust air and a 60% higher volume flow. The savings on a percentage basis in fan electricity are still higher, as the pressure drops in AHU and ductwork in proportion to $(50,4/80)^2 = 0,4$ and primary pressure from 300 to 100Pa.

energy demand and costs	Version V0 - before refurbishment	Version V1 - new terminals - CAV	Version V2 - new terminals - DCV	electricity: 0,15€/kWh heating: 0,06€/kWh
mode of operation	CAV	CAV	DCV	
mean primary flow rate	80	50,4	32	m³/h/unit
primary pressure	300	100	100	Pa
SFP-extract fan	1200	676	429	W/(m³/s)
SFP-supply fan	2600	994	631	W/(m³/s)
demand of electricity per unit	274	76	31	kWh/unit/a
electricity cost per unit	41 €	11 €	5 €	€/unit
heat recovery	20% UML	0,5	0,5	recov. coeff.
ventilation heat loss (20°C)	2418	1130	718	kWh/unit/a
heating costs per unit	145 €	68 €	43 €	per unit
sum of energy costs	186 €	79 €	48 €	per unit
annual savings [€/a]	- €	107 €	139 €	per unit
annual savings [%]	0%	57%	74%	per unit

Tab. 1: Comparison of energy costs

The second version (V2) displays the benefits of demand controlled ventilation by an extra savings in heat and electricity proportional to the reduction of air volume rate in the CAV and DCV mode (fig.8).

Cost effectiveness of DCV induction systems

In this comparison, the total annual cost is the sum of cost for

- electric energy for fans
- central ventilation heat
- maintenance of induction units
- annual capital costs with 9% annuity

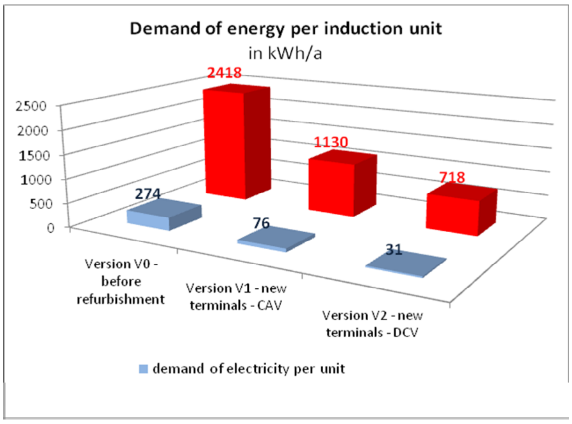


Fig. 8: Comparison of energy demand

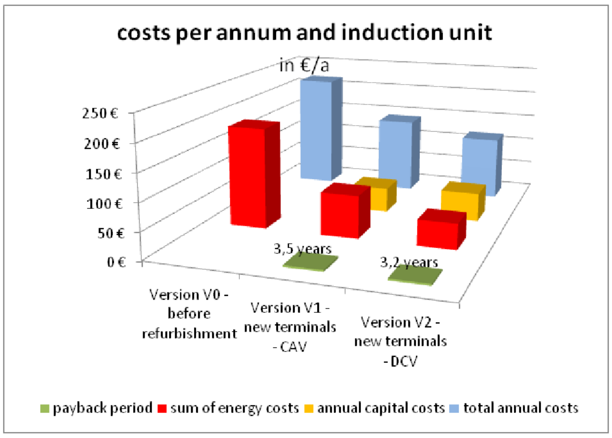


Fig. 9: Comparison of costs

The payback period is based on depreciation over 10 years. The first costs for DCV-control is calculated with a two-stage primary volume rate, the control equipment as a group of one room thermostat connected with three terminals units. Fig. 9 shows the highest savings with the first step to a CAV-System and minimal air rates. The DCV-system is still economic. The energy economy compensates the higher costs for the control equipment

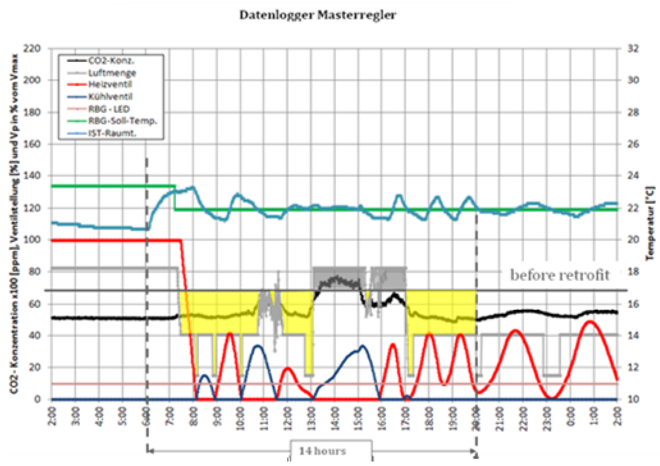


Fig. 10: 24-hrs-plot of DCV-units in conferennce room

For conference rooms a steady air quality controller is recommended. The plot in fig. 10 demonstrates the interaction of temperature and air quality control in a conference room. The yellow colored spaces select the savings of volume flow in contrast to the constant primary air rate before retrofit. When we assume in our example, that 15% of the office floor space is used for conference, the first costs will increase in the same region and the payback period for CAV and DCV will be equal. However, the main difference and advantage are the flexibility of DCV. CAV-design at hygienic minimum often provokes a low indoor air quality, when visitors enter a room. DCV-system adapt outdoor air rates to activity, the primary air "follows" the persons.

	version 2 CAV manually adjust-able flow rate	version 3a DCV 2-stage primary flow control	version 3b DCV stepless primary flow control
non-flammable material, induction nozzles	●	●	●
retrofitting during building operation	●	●●	●●●
decentral air conditioning in zones of floor space	●	●	●
adaption to changes in office floor space and use	●	●●	●●
DCV flow control for AHU and induction terminals		●	●
indoor air quality control by CO_2–sensor, presence detect.		●	●
low sound power level	●	●	●
high thermal comfort by mixing & displacement ventilation	●	●●	●●
flow field adaption by actuator		●	●
energy conservation by low primary pressure and DCV	●	●●	●●●

Tab. 2: Main characteristics for CAV- and DCV induction systems

In table 2 specifies the main characteristics of the new induction system. In an office building all of these three types of terminal units can be applied. The mechanical construction of the units is identical. The versions differ by control equipment and can be easily converted from CAV to DCV-mode.

Conclusions

The retrofit of an induction system by new induction terminals and the further use of existing air handling units and the air and water distribution can be the best solution for an office building. As primary air rate of induction system is linked to water based thermal capacity, a design at minimal outdoor air rates or any other fixed volume flow is inflexible due to office activities. Demand controlled ventilation allows higher primary airflow rates when occupancy increases. Occupancy is linked with heat gains. The main advantages of DCV are good thermal comfort and indoor air quality with a minimum input of energy.

New induction units of the third generation adapt their flow field to the loads in the room for reasons of low draft risk and high ventilation efficiency. At higher primary air rates, the induction of secondary air is reduced. A part of the primary volume flow is diffused with low velocity, without passing heat exchanger and injector. The occupant can influence his favorite temperature and outdoor air rate. When he opens the window, primary air is cut off by CO_2-sensor.

For the evaluation of the German "Energiepass", the primary energy demand of refurbished induction systems can be below the demand of a reference office building – as a benchmark of new buildings. DCV-induction systems are - last but not least- an economic and sustainable solution for new office buildings, when cooling loads can be conveyed by minimal hygienic outdoor air rates.

References

[1] J. Masuch, W. Steinbach. Energieverbrauchsrechnung zur Optimierung von Klimaanlagensystemen. LTG Technische Information 31 (1976)

[2] W. Hönmann. Raumlufttechnik und Energieverbrauch. LTG Technische Information 61 (1986)

[3] ISO 7730. Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (2005)

[4] VDI 3804. Air-conditioning – office buildings (2009-03). VDI-Gesellschaft Bauen und Gebäudetechnik

[5] DIN V 18599. Energetische Bewertung von Gebäuden; Berechnung des Nutz-, End-, Primärenergiebedarfs für Heizen, Kühlen, Lüften...(2011)

[6] DIN EN 15251. Input environmental parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics (2007)

[7] http://ltg-ag.de/fileadmin/_temp_/downloads/dokumentationen/raumlufttechnik/luft-wasser-systeme/induktionsgeraete_klimavent/KI-Induktionsgeraet_HFVsf.pdf (2011)

Natural night ventilation as passive design strategy for a Net Zero Energy office building

Annamaria Belleri[12], Marco Castagna[1], Roberto Lollini[1]

Institute for Renewable Energy - EURAC research[1], Università degli Studi di Bergamo[2]

Abstract

The paper describes the case study of one of the new buildings placed in the new Technology Park in Bolzano (Italy). To achieve the targets of Net Zero Energy Building and total primary energy index lower than 60 kWh/m^{2}y, natural ventilation has been considered as a passive solution to reduce cooling needs and operation costs. As it depends on building envelope, indoor spaces layout and components sizing, natural ventilation has been taken into account since the early stage of design.

Thanks to an integrated design process, shared solution was found out that balances performances needs with constrains given by fire regulations, acoustic comfort and user's needs, and to satisfactorily maintain the architectural impact of the solution.

Outdoor environmental conditions have been analyzed and climate potentials for driving natural ventilation have been estimated. Considering building occupation, user comfort needs and climate, a night ventilation strategy has been chosen as the most suitable for the case.

A simplified airflow model was used to assess the design solutions, suggested inside the integrated design process, and to fix the minimum opening area that allows achieving the requested airflow rates. Then, a dynamic energy simulation model was run to assess the potential energy savings thanks to the night ventilation cooling and to estimate the cooling needs reduction.

Obtained results showed how natural ventilation can meaningful contribute to the cooling needs and overall primary energy consumption reduction, contributing to the fixed energy performance targets.

Introduction

The paper describes the case study of one of the new buildings placed in the new Technology Park in Bolzano (Italy). The project aims at regenerating an old industrial area, where three main existing blocks listed as industrial historical buildings will be renovated and other new buildings will be built. For the above mentioned building owner and design team have taken up the challenge to achieve the targets of Net Zero Energy Building and total primary energy index lower than 60 kWh/m^{2}y.

The building is architecturally conceived as a black monolithic block with a nearly-square plant. It has five floors and an underground floor. The main entrance is on the north side of the ground floor and on the south side there is the expo area. The upper floors will host offices, meetings rooms and service rooms, whereas in the underground floor there will be several conference rooms with direct external entrances. In the centre of the building and through the full height, a green patio is designed as a buffer zone to improve indoor comfort and daylighting.

The envelope is a metal-glass façade with a solar shading system in the south façade and a black surface with different series of horizontal windows in the other facades. The horizontal windows on north, east and west façade are positioned on the inner side of the external wall. In this way, the deep reveal due to the wall thickness and the low height of the windows work as a sun shading system and the glazed part of the façade will not be visible from the outside perspective.

Render of the building
CLEAA – Claudio Lucchin E Architetti Associati

The ambitious targets could be reached considering first of all the reduction of energy needs, in particular through passive solutions. The paper presents natural ventilation as a passive solution to reduce cooling needs and operation costs. Different natural ventilation strategies were analyzed:

- daytime ventilation
- night cooling
- ground cooling

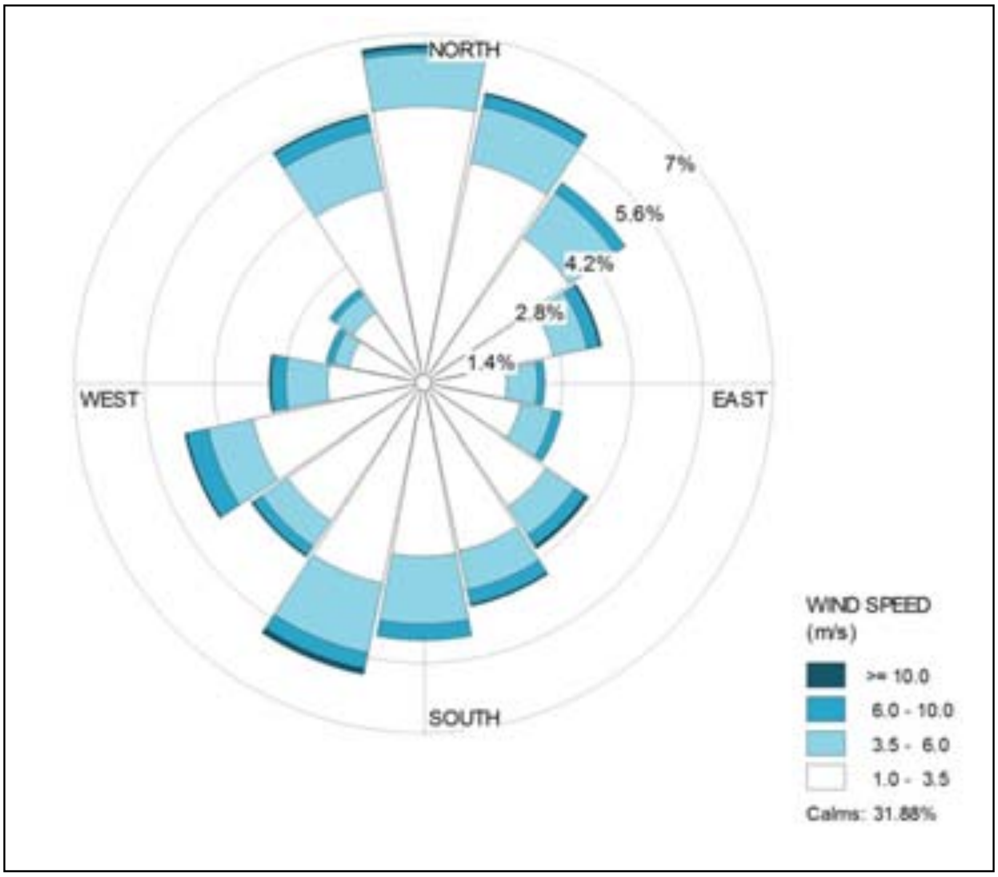
Windows cannot be opened during the occupancy period because of traffic noise or high air speed and therefore daytime ventilation is not feasible. Due to the high relative humidity rate during the summer in Bolzano, ground cooling could not be suggested because of possible air saturation problems caused by temperature decrease. Therefore, passive night cooling was proposed as the most reliable and easy solution to reduce HVAC working hours. The effectiveness of this solution increases if the following conditions are met:

- solar gains reduction through high thermal insulation and shading systems;
- internal loads reduction through low consumption appliances and lighting control;
- thermal capacity exploitation through exposed ceiling mass.

Climate potential analysis

As a starting point a climate analysis was carried out on the natural ventilation driving forces (hourly air-temperature and wind speed and direction) to verify the potential cooling need reduction of a night cooling strategy.

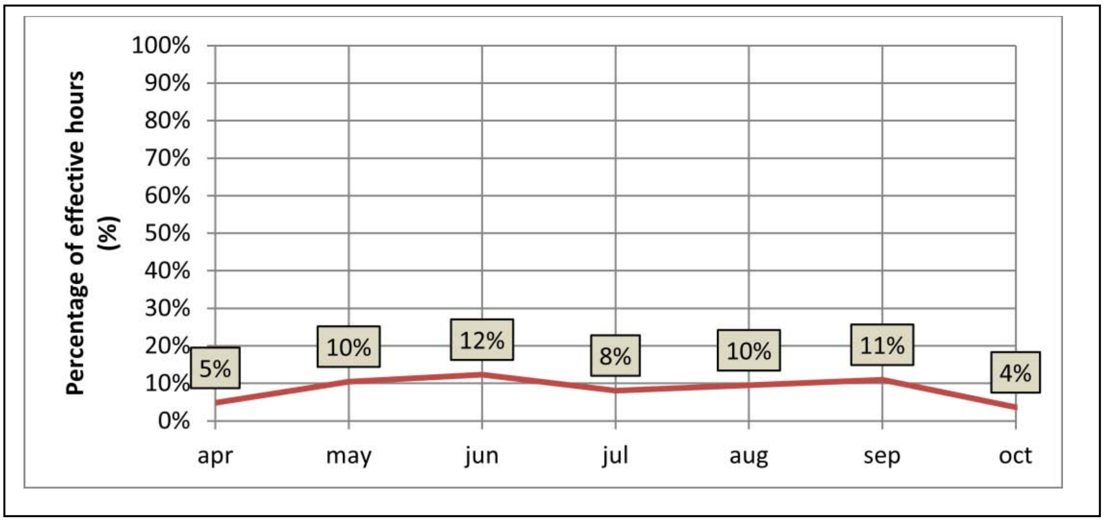
The wind rose shows that circa 30% of the night hours are calms and in the 80% of the night hours wind speed is under 3.5 m/s; wind-driven cross ventilation could not be always assured.



Wind rose for Bolzano during the night hours (6pm – 8am) in the cooling period (15/04 - 14/10)
Lakes Environmental WRPLOT [1]

Therefore, stack driven cross ventilation was outlined as the most effective configuration. To estimate the number of effective hours the following activation conditions were assumed:

- From 6 pm to 8 am
- External temperature between 14°C and 26°C
- Dew point temperature lower than or equal to 17°C



Number of effective hours in the activation condition for passive night cooling during the cooling season
Weather data registered by the EURAC monitored weather station at Bolzano in 2010

It is a rough analysis to estimate the potential of passive night cooling and only few input data about the building are needed. “Climatic Cooling Potential”, defined by Artmann N. [2] as a summation of products between building/external air temperature-difference and time interval, has been estimated as:

$$CCP = \frac{1}{N}\sum_{n=1}^{N}\sum_{h=h_s}^{h_f} m_{n,h}\left(T_{b,n,h} - T_{e,n,h}\right) \qquad \begin{cases} m = 1 & if\ 14°C \leq T_e \leq 26°C \\ m = 0 & other \end{cases}$$

where

T_b = building air temperature

T_e = external air temperature

N = number of nights

h = time of the day (h_i and h_f denote the initial and the final time of night-time ventilation)

The heat flux $\dot{q}$ which could be potentially rejected per CCP - Degree Hour can be calculated as:

$$\frac{\dot{q}}{CCP} = \frac{\rho c_p H\ ACH}{3600\ t_{occ}} \quad \left[\frac{W/_{m^2}}{Kh}\right]$$

where

t_{occ} = time of building occupancy

H = floor height

Assuming airflow of 2 ACH to avoid too high air velocities, the heat that could be rejected is 12 W/m^2. Considering that the expected total internal heat gains[1] will be around 40 W/m^2, maximum 29% of the total internal heat gains could be potentially offset through a night cooling strategy.

This method allowed the building designer to quickly evaluate the potential effectiveness of night cooling strategies, given knowledge of the likely internal gains in the building and the estimation about the airflow rates. It has to be considered only as a preliminary analysis on the assumption that:

- thermal capacity of the building mass is sufficiently high and therefore does not limit the heat storage process;
- building temperature oscillates harmonically to simulate the dynamic effect of heat storage in the structure materials.

---

[1] The internal heat gains can be considered particularly low because of an effective shading system and energy efficient lighting system and electrical equipment.

Constraints analysis

As natural ventilation influences building envelope design, indoor spaces layout and components sizing, a shared natural ventilation solution from architectural and constructive point of view has been found out through the integrated design process. The agreed solution balances performance needs with constrains given by fire regulations, acoustic comfort and user's needs, and to keep acceptable the architectural impact of the solution.

To maintain the indoor spaces layout flexibility it was not possible to plan ventilation shaft or stack devices and to estimate accurately the pressure drops due to the internal walls and vent size.

Furthermore, the plan of natural ventilation has to strictly comply with fire regulations and plans. The building is divided into fire compartments enclosed with a fire resistive construction that have to be by definition air tight or closable. A natural ventilation configuration that involves more fire compartments should use components with high fire resistance ratings. Due to the high additional costs it was decided to study a natural ventilation configuration for every fire compartment.

Furthermore, acoustic problems due to air connections between offices and plans should not be neglected as the future users need privacy during the working hours.

Another constraint was about the architectural impact of the solutions. The monolithic block feature has to be maintained by reducing as much as possible the movable part in the façade, openable windows included.

Airflow models in the Integrated Design Process

As building design is characterized by even more detailed design level, airflow model with different detail level needs should be used to support the decision-making process.

Available airflow models can be divided into three categories:

- Empirical models
- Network airflow models
- Computational Fluid Dynamics (CFD)

Empirical models are basically static correlations derived analytically or experimentally to predict ventilation airflow rates for simple opening configuration. They aim at sizing airflow, openings or air velocity. As they refer to a limited number of case studies, they are based on many assumptions. A review of the existing main empirical models can be found in [3] and [4].

Airflow network models have been developed to more quickly solve airflows throughout a building. They represent the building with one or more well-mixed zones, assumed to have a uniform temperature and a pressure varying hydrostatically, connected by one or more airflow paths. Each airflow path is mathematically described using the Bernoulli equation. A matrix of the equation is constructed and numerically solved. Convergence is reached when the sum of all mass flow rates through all components approaches zero within the tolerance band specified [3]. The most commonly models used are COMIS [5] and CONTAM [6].

These models can be coupled to dynamic simulation models to evaluate the whole building performance [4], taking into account the thermal mass effect as well. Different coupling approaches are possible [7]. Despite their simplicity, airflow network models have some important limitations:

- heavily dependency on coefficients like wind profile exponent, pressure coefficients and discharge coefficients;
- turbulent fluctuations of wind pressures are neglected [8];
- air speed in rooms cannot be calculated.

As stated by the experiences described in ASHRAE TRP-1456 [4], the network models are able to predict indoor temperatures within 30% error in general compared with measured data in laboratory experiments.

CFD aims at solving the Navier-Stokes equation in a fluid domain and can provide detail information about air velocity, temperature and pressure distribution at each point of the zone. Given the long calculation time and the high dependency on boundary condition, CFD simulations should be successfully applied only at an advanced design level to verify indoor comfort. Thermal domain and detailed airflow domain can also be coupled to achieve better results because the two can provide boundary conditions to each other [9].

Natural ventilation configuration

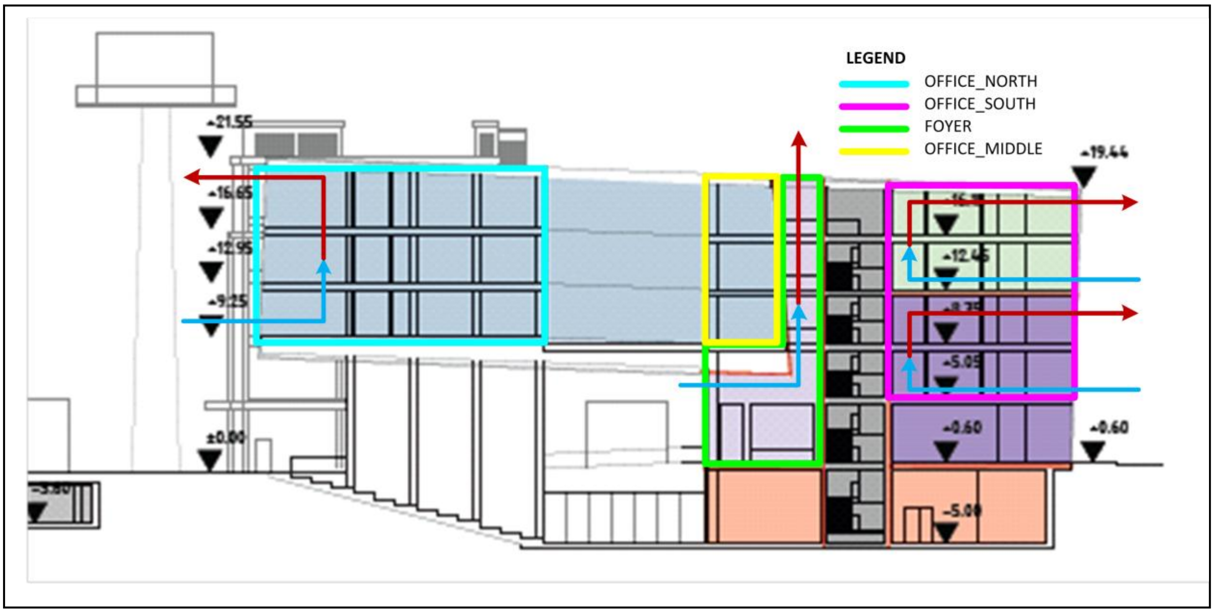
A stack driven cross ventilation was chosen as the most effective configuration that balances performances needs with constrains given by fire compartments, acoustic comfort and privacy needs in the offices during the working hours.

To increase the height difference between inlet and outlet openings, connecting floor vents will be applied. This solution keeps acceptable the architectural impact by reducing the movable part in the façade and by keeping free the internal layout of the spaces. The floor vents can be closed during the working hours to avoid acoustic discomfort and maintain privacy between offices.

An example of corridor inlet vents (left) and atria connecting floor vents (right), installed for natural ventilation of the Concordia University building in Montreal (Canada)
Source: Mouriki E. [10]

The foyer is directly connected to a lightwell and to the hall of every floor and is ventilated through a stack driven cross ventilation that allows avoiding overheating.

Due to safety reasons underground floor and expo areas are mechanically ventilated. A small office area in the center part of the building is single-sided ventilated and connected with the green patio.



Cross section of the building from fire regulation plan with fire compartments, model zones and a scheme of the selected stack-driven cross ventilation configurations for the considered zones

Fire compartments are filled with different colors whereas the selected zones for natural ventilation configurations are outlined with the colors indicated in the legend. Airflow paths are designed as well.

Once opening position was roughly configured, minimum openings area was sized through the ASHRAE equation for flow caused by thermal forces only [11], as follows.

$$Q = c_d A \sqrt{2g\Delta H_{NPL}\frac{T_i - T_o}{T_i}}\frac{3600}{V} = Z\sqrt{\frac{T_i - T_o}{T_i}}$$

- Q = airflow rate [vol/h]
- c_d = discharge coefficient
- ΔH_{NPL} = height from midpoint of lower opening to Neutral Pressure Level [m]
- A = cross sectional area of inlet and outlet opening [m²]
- V = zone volume [m^3]

The equation terms dependent on building geometry and opening position were assumed equal to a constant Z. The constant Z was estimated by fixing a maximum airflow rate of 2 ACH and assessing the dynamic terms of the equation through a simulation in Trnsys [12].

Minimum opening area estimated for every building zone

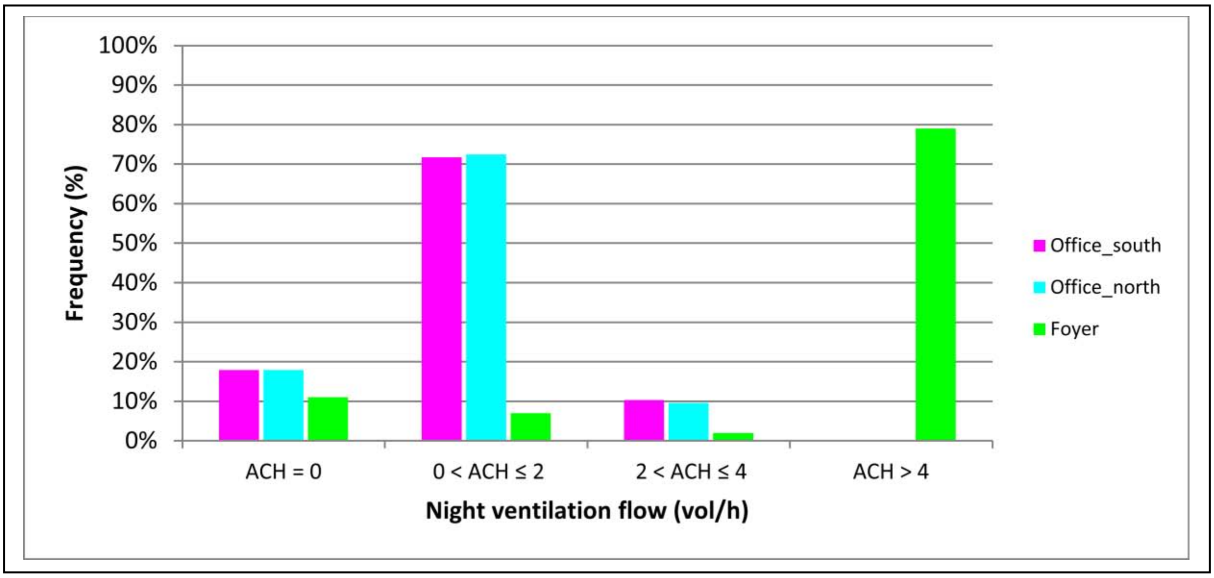
Zone	Inlet area [m^2]	Outlet area [m^2]	Floor vents area [m^2]
Office_south	3.2	3.2	6.4
Office_north	10.5	10.5	21
Foyer	10	10	-

To assess the airflow paths a transient analysis was performed by the CONTAM airflow model. As the model does not handle with heat transfer phenomena, a model was performed separately for every zone.

The models were simplified by neglecting wind effects and air leakages. Internal building layout was not considered, as it was not yet defined. For façade openings airflow is represented in CONTAM by an equivalent flow through a flat plate orifice through the Powerlaw Model. Floor vents are modelled through the Stairwell version of the Powerlaw Model [6].

Building temperature is scheduled daily and assumed to oscillate harmonically to simulate the dynamic effect of heat storage in the structure materials. Occupancy is set from 8 am to 6 pm during working days only. Windows opening is activated only when external temperature is between 14°C and 26°C during the night. As control signal will take precedence over the schedule, results data was elaborated to cut the day hours.

CONTAM is an advantageous tool for natural ventilation design to assess bulk airflow rate and verify the configuration suitability. Positive flow direction was set in the wanted flow way, so that negative airflow indicates an unwanted flow direction. Pressure difference and flow direction was plotted for every airflow path to check the flow direction and verify the configuration concept. Flow direction resulted negative in less than 1% of the night hours.

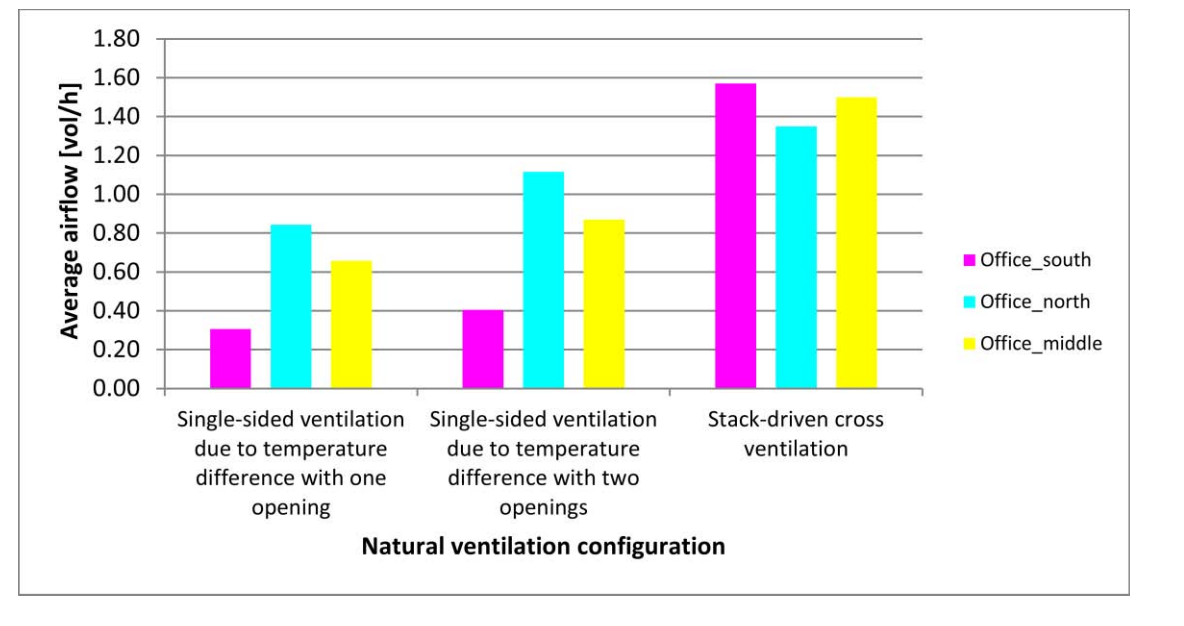


ACH frequency in the building zones during night (from June to September) thanks to the natural ventilation
CONTAM simulation results elaboration

As the graph shows in north and south office zone, the airflow rate is between 0 and 2 ACH for the 70% of the night hours, whereas the airflow rate in the foyer zone are higher because of the openings elevation difference that enhances the stack effect.

A comparison was performed between the chosen solution and other allowable solutions, like single-sided ventilation due to temperature difference with one opening or with two openings at different elevation. The configurations were compared for a floor type and for the same opening area and a fixed opening height of 50 cm, to prove the architect that the solution proposed has better performance than other solutions with the same architectural impact.

The central office area cannot be connected with the lightwell because of the fire regulation plan. Single-sided ventilation will be here configured.



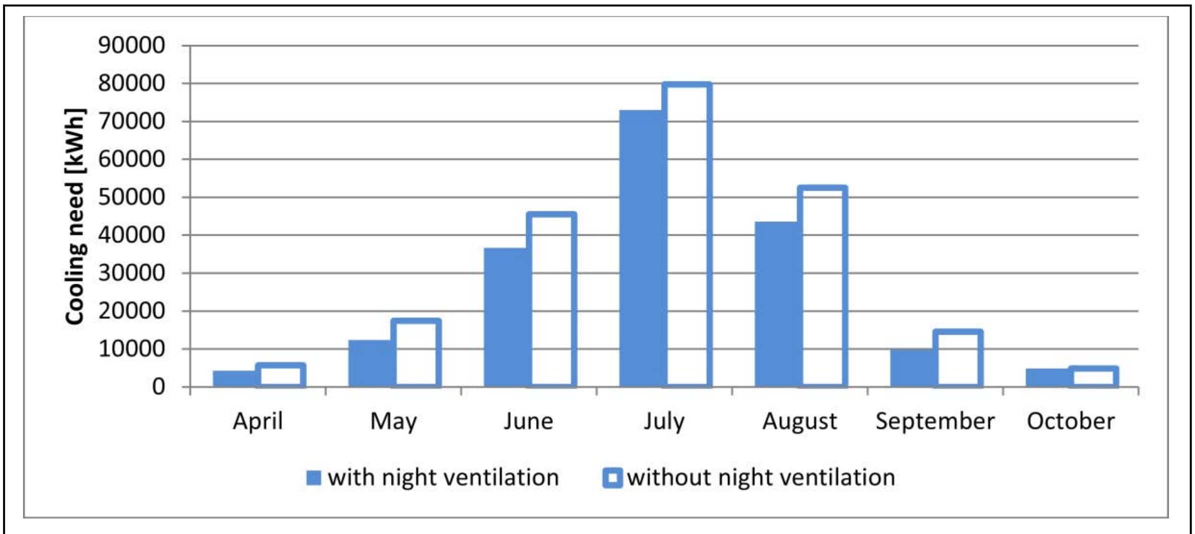
Comparison between the allowable natural ventilation configuration solutions for the same opening area in a floor type
Airflow due to single-sided ventilation with one and two openings has been estimated through the BS 5925:1991 [13] formulas. Stack-driven cross ventilation effect has been estimated with CONTAM airflow model [6].

Once opening area was sized, building energy simulations, with and without natural ventilation, were run to estimate the night cooling effect on the whole building performance. Dynamic simulations were performed by Trnsys 17 [12] with the following openings activation thresholds:

- from 6 pm to 8 am
- $14°C < T_{out} < T_{in}$
- $T_{in} > 24°C$
- $T_{out\text{-}dp} \leq 17°C$

The air humidity control was introduced to avoid an air absolute humidity higher than the comfort one (air temperature of 26°C with relative humidity of 60%).

Due to night cooling the cooling need reduction was estimated around 15%.



Dynamic simulation results comparison between monthly cooling need with and without night ventilation.
Dynamic simulations performed in Trnsys show a total cooling need reduction of about 15%.

Discussion and outlook

The assumptions made for the assessment of the natural ventilation strategy allowed performing a simplified analysis on night cooling strategies. The comparison confirms that the solution proposed gives better performances than single-sided ventilation, considering the constraints given. The rough cooling need reduction estimation has to be proven with more detailed simulation and further more by (foreseen) monitoring.

As the design becomes more and more detailed, more detailed simulations have to be performed with less assumption on input data. Pressures lost along the airflow path have to be assessed. Airflow and thermal model will be coupled to consider the thermal mass effect and the real internal temperature fluctuation.

In the early stage climate evaluation wind was not taken into account, because the available wind directions, velocities and frequency did not allow designing a wind-driven natural ventilation configuration. However, wind can affect negatively or positively the found results. An urban CFD study should be performed to understand the possible wind impact on air velocities and pressure around the building. More accurate climate data are needed, as Bolzano is placed where two valleys meet and prevailing wind direction can vary significantly from one part of the city to another.

The more accurate wind analysis aims at evaluating the dependency of the control strategy on wind direction and velocity. The control strategy will allow through a windows automation system a programmed opening/closing of windows group controlled by indoor temperature, outdoor temperature and humidity, as in dynamic simulations settings.

Conclusion

The paper highlights the fundamental importance of an integrated design process to conceive a natural ventilation strategy that can meaningful contribute to the cooling needs and the overall primary energy consumption reduction towards a Net Zero Energy building.

Main design professionals (owner, designer, consultants) worked together to find out a shared solution that balances performances needs with constrains given by fire regulations, acoustic comfort and user’s needs, and to keep acceptable the architectural impact of the solution. Qualitative and quantitative analysis were performed to support the decision process in the early stage of the design.

First, the potential effectiveness of night cooling strategies was analyzed. Taking into account the constraints given, allowable natural ventilation configurations were suggested and compared. Minimum opening area needed to obtain the desired airflow was sized. Trnsys was used to perform a comparison between the baseline model and the natural ventilation model. Obtained results showed how the potential cooling need reduction of the night cooling strategy suggested is around 15%.

It is recognised that natural ventilation design could give an important contribution to achieve the Net Zero Energy target, without increasing significantly operation and construction costs.

Acknowledgments

The authors wish to thank the Province of Bolzano and the design team CLEAA for having responded to the challenge of this ambitious target in a very cooperative and positive way.

References

[1] Lakes Environmental WRPLOT View – Version 7.0.0, http://www.weblakes.com/

[2] Artmann N., Manz H., Heiselberg P. *Climatic potential for passive cooling of buildings by night-time ventilation in Europe.* 187-201, Applied energy, 2007, Vol. 84.

[3] Allard F., Santamouris M. *Natural ventilation in building design - A design handbook*. 1998.

[4] Zhai J., Krarti M., Johnson M.H. *Assess and implement natural and hybrid ventilation models in whole-building energy simulations.* ASHRAE TRP-1456: Department of Civil, Environmental and Architectural Engineering, University of Colorado, 2010.

[5] Warren P. *Multizone Airflow Modelling (COMIS).* Summary of IEA Annex 23, 1996.

[6] Walton G.N., Dols W.S. *CONTAM - User guide and program documentation.* NISTIR - 7251: NIST - National Institute of Standard and Technology, 2010.

[7] Hensen J.L.M. *Modelling coupled heat and airflow: Ping-pong vs onions.* Proceedings of the 16th AIVC Conference "Implementing the Results of Ventilation Research" (Palm Springs, 1995.), pp. 253-262.

[8] Caciolo M., Marchio D., Stabat P. *Survey of the existing approaches to assess and design natural ventilation and need for further developments.* 11th International IBPSA Conference (Glasgow, 2009), pp. 220-227.

[9] Ery Djunaedy *External coupling between building energy simulation and computational fluid dynamics.* TU Eindhoven, 2005.

[10] Mouriki E., Karava P., Park K-W., Athienitis A., Stathopoulos T. *Full-scale study of a hybrid ventilation system integrated with an atrium - night cooling potential.* 4th Canadian Solar Buildings Conference (Toronto, 2009).

[11] *ASHRAE Handbook of fundamentals*. Ch. 16.13, eq. 38, 2009.

[12] http://www.trnsys.com/. Transient system simulation tool, version 17, 2011.

[13] BS 5925:1991 *Code of practice for ventilation principles and designing for natural ventilation.*

A Predictive Nighttime Ventilation Algorithm to Reduce Energy Use and Peak Demand in an Office Building

Hatef Aria and Hashem Akbari*
Department of Building, Civil and Environmental Engineering Concordia University

Abstract

We investigate the effect of two nighttime ventilation strategies on cooling and heating energy use for a prototype office building in several northern America climates, using DOE2.1E building energy simulation program . The strategies include: (1) a scheduled-driven nighttime ventilation that is applied only during the summer and (2) a predictive method for nighttime ventilation that is applied for the entire year. The maximum possible energy savings and peak demand reduction in each climate is analyzed as a function of ventilation rate, indoor-outdoor temperature difference, and building thermal mass.

The results show that nighttime ventilation could save up to 32% cooling energy in an office building, while, the total energy savings for the fan and cooling is less than 13%. In addition nighttime ventilation strategies could reduce peak demand for both cooling and fan energy consumption by about 10%. The energy consumption of ventilation fan reduces the total amount of energy savings, or even could lead to increasing the overall air conditioning energy use. Consequently, finding the optimal control parameters for the nighttime ventilation strategies is very important. The performance of the two strategies varies in different climates. The predictive nighttime ventilation worked better in weather conditions with fairly smooth transition from heating to cooling season. When the winter to summer transition was not smooth, the simple scheduled nighttime ventilation produced better results.

Introduction

Nighttime ventilation is a strategy that can be used for reducing cooling energy in buildings. Many studies have investigated the effect of nighttime ventilation in moderate, continental, and Mediterranean climates [2-5]. The nighttime ventilation strategy uses the nighttime outdoor cold air by means of natural and/or mechanical ventilation to cool the thermal mass of the building. The cooled thermal mass then is used as a heat sink during the next day. For mechanical nighttime ventilation a fan is needed to allow a better control for the outside air ventilation. The energy use by the fan, in turn, reduces the potential cooling energy savings. Another strategy that can improve energy savings in the building is dynamically changing the cooling set-point temperature of the building throughout the day [6-8]. This strategy is referred to as “pre-cooling

Nighttime ventilation effectiveness related parameters are classified into three main categories [9-11]: building parameters (thermal mass), technical parameters (outdoor air flow rate, nighttime ventilation duration and temperature difference), and climatic parameters (outside temperature, humidity, and solar radiation). Higher nighttime ventilation flow rate and duration increase cooling energy that stored in the building, also they increase fan energy consumption. For nighttime ventilation to be effective, building thermal mass is a necessary requirement that in its absence nighttime ventilation is not efficient. In an optimal control operation, all these parameters need to be considered.

Various studies evaluated the effect of different parameters such as climate, air flow rate, and thermal mass, on effectiveness of nighttime ventilation and occupant comfort [12-15]. However, fewer studies considered duration of nighttime ventilation [16, 17]. Most studies have focused on the effect of nighttime

***Corresponding Author**

HAkbari@ENCS.CONCORDIA.CA
514-848-2424 X3201

ventilation in hot or moderate climates while effectiveness of nighttime ventilation in cold climates needs more investigation [18].

Finn et al. [19] assessed the role of different building design and operational parameters on peak daily temperature of a non-airconditioned, nighttime ventilated library building in a maritime climate; their results showed up to 2°C decrease in peak internal day temperature. Gratia et al. [3] observed that for moderate climates, nighttime ventilation can offset cooling loads in the order of 30%. They investigated the size, shape and location of the window apertures to reach sufficient ventilation rates for nighttime ventilation. They also analyzed the effect of wind direction and surrounding buildings on natural ventilation rates.

Wang et al. [17] evaluated the important factors influencing nighttime ventilation performance such as ventilation rate and duration, building mass, and climatic conditions. They used EnergyPlus to simulate the indoor thermal environment and energy consumption in typical office buildings with mechanical nighttime ventilation in three cities in northern China. Their results showed that more energy is saved in office buildings cooled by a nighttime ventilation system in northern China than those that did not employ this strategy. Artmann et al. [13] simulated a typical office building room and evaluated the effect of different parameters for nighttime ventilation such as building construction, internal heat gains, air change rates, heat transfer coefficients, and climatic conditions on the number of overheating degree hours. Using the number of overheating degree hours, they demonstrated the effectiveness of different night ventilation air change rates and heat transfer between the internal surfaces and the room air.

The objective of this paper is to assess the performance of mechanical nighttime ventilation cooling and optimize the control strategies in typical conditioned office buildings in North America. An hourly building energy simulation model, DOE2.1E [1,20], was used to investigate the potential for improving indoor environment and energy savings. In addition, the effect of different parameters was studied to evaluate the effectiveness of nighttime ventilation techniques as a function of flow rate and indoor-outdoor temperature difference in several climate conditions.

Method

Our methodology included parametric simulations of a typical small office building to estimate the total heating and cooling energy use of the building. Two nighttime ventilation strategies were used: DOE2 built in schedules and a predictive algorithm to allow nighttime ventilation based on the predicted next day outdoor temperature. DOE2 default algorithm requires the operator pre-defined schedules (that varies by climate region) for heating and cooling of the building. Our predictive algorithm allows for nighttime ventilation throughout the year for all climate regions.

Building model

The prototypical building is a typical one-story office building with 5 zones and plenum, Table 1. The total floor area is 464.5 m^2 (5000 ft^2) with a height of 2.4 m (8 ft). There is no shelter from other nearby facilities. The building was built with medium weight construction.

Interior loads are surface mounted fluorescent lighting at 16 W/m^2, equipment at 10.8 W/m^2, and people at 9.3 m^2 (100 ft^2) per person. Infiltration is at 0.25 air changes per hour (ACH). Design temperatures for cooling and heating are set to 25.5°C (78 °F), and 21°C (70 °F), respectively. A single variable air volume system serves the entire building. The system has a drybulb controlled economizer with a limit temperature of 18.3°C (65 °F), variable speed fan motor, and VAV boxes with a minimum stop of 30%. The system operates from 8am to 6pm weekdays and is off during nights and weekends. There is a nighttime and weekend low limit set-point of 12.8°C (55 °F) to prevent freezing. HVAC plant works with gas fired hot water generator and reciprocating air cooled chiller. Detail of building construction and loads are shown in Table 2.

A value of roof insulation was taken to represent many existing buildings with low (or no) insulation. It is expected that nighttime ventilation to be more effective in highly insulated buildings. We simulate the potential of nighttime ventilation with different level of roof insulation and indeed demonstrating this point.

Table1: detail description of each zone in the building

Zoom number	Type	Area m^2 (ft^2)	Volume m^3 (ft^3)	Occupants
1	Office	98 (1056)	239 (8448)	11
2	Office	42 (456)	103 (3648)	5
3	Office	98 (1056)	239 (8448)	11
4	Office	42 (456)	103 (3648)	5
5	Office	183.5 (1976)	447.6 (15808)	20
6	Plenum	464.5 (5000)	283 (10000)	0

Table 2: Detail of building description

Parameters	Description
Floor area m^2 (ft^2)	464.5 (5000)
Wall construction	Wood shingles, plywood, R-11 fiber insulation, gypsum board
Roof construction	Roof gravel, built-up roofing,R-3 mineral board insulation, wood sheathing ceiling
Window glass	¼ in plate double pane
Door glass	½ in plate single pane
Interior loads	Lighting=16 W/m^2, equipment = 10.8 W/m^2, people = 100 ft^2 per person
Interior partitions W/m^2 K (BTU/hr ft^2 F)	U-value = 8.5 (1.5)
Infiltration	0.25 ACH
Chiller	Reciprocating air cooled chiller (COP=3.65)
Boiler	Gas fired hot water boiler (EFF = 85%)

External temperature conditions

Nighttime ventilation is used to circulate outdoor cold air to cool the surface of the building envelope and indoor items. Outdoor temperature has a strong effect on the effectiveness of ventilation. During the air conditioning period, from June 1 to August 31, the maximum, minimum and average outside air temperatures are shown in Table 3 for different cities. These cities are chosen as examples for very cold (Montreal), cold (Victoria), and moderate (Portland) climates in North America.

Table 3: The maximum, minimum and average outside air temperatures for investigated cities

	Jun			Jul			Aug		
City	**Max T °C(°F)**	**Min T °C (°F)**	**Ave T °C (°F)**	**Max T °C (°F)**	**Min T °C (°F)**	**Ave T °C (°F)**	**Max T °C (°F)**	**Min T °C (°F)**	**Ave T °C (°F)**
Montreal	30 (86)	7.2 (45)	18.5 (65.4)	31.6 (89)	8.3 (47)	20.7 (69.2)	28.9 (84)	7.7 (46)	19.5 (67.2)
Victoria	23.8 (75)	7.7 (46)	14.3 (57.7)	28.8 (84)	6.6 (44)	15.8 (60.4)	28.9 (84)	7.7 (46)	16 (60.9)
Portland	33.3 (92)	9.4 (49)	17.5 (63.6)	37.8 (100)	12.2 (54)	19.9 (67.8)	36.7 (98)	11.1 (52)	20.1 (68.2)

Strategies and Parameters

The strategies investigated are:

1. Scheduled nighttime ventilation during summer (as defined by the building operator)
2. Nighttime ventilation using a predictive algorithm applied to the entire year
3. Pre-cooling of the building during morning hours and allowing the temperature to gradually increase to the set-point temperature in the afternoon
4. Pre-cooling + Nighttime ventilation cooling

(1) Scheduled-driven ventilation during summer. In this strategy without respect to outside temperature and building cooling or heating mode, ventilation fan brings in outside air from midnight till beginning of the working hour with a constant air flow rate to cool the building. In our investigations this fixed schedule is set to three months of Jun, July, and August that leads to most possible energy savings.

(2) Predictive method for nighttime ventilation applied to the entire year. In this method we add a function to DOE21E to changing the fan ventilation working hours according to the prediction of the next day outside air temperature. Based on today's minimum and maximum outside temperature and trend of temperature during hours 21-24, we predict average, maximum, and minimum outside temperature for the next day (Eq 1 and 2) [21]. The equations are developed through regressions of temperature data and minimizing the error of estimates for predicted temperatures for the summer period. This type of predictive algorithms can be improved through a more thorough analysis of building-related weather data in different climates. This strategy uses predicted temperatures and the cooling characteristics of our building, to decide whether to have nighttime ventilation and duration of ventilation (Eq 3). Figure 1 shows the control strategy of this method.

$$TP_{Min} = 0.659\ T_{max} + 0.307\ T(24) - 0.184[T(20) - T(22)] \quad (1)$$

$$TP_{Max} = T_{max} + 0.349[T(21) - T(21\ PRE)] - 0.1[T(20) - T(22)] \quad (2)$$

Where
T(x): outside temperature at hour (x)

T(x PRE): outside temperature at hour (x) for previous day

T_Min and T_Max: minimum and maximum outside temperature

TP_Min and TP_Max: minimum and maximum predicted outside temperature for next day.

$$TP - Ave = \frac{TP - Min + TP - Max}{2}$$

$$Predictive\ Strategy \begin{cases} \mathbf{TP - Ave < 16\ °C} \rightarrow No\ Nighttime\ Ventilation \\ \mathbf{16\ °C} < TP - Ave < \mathbf{17.5\ °C} \rightarrow NV\ from\ \mathbf{3}am\ to\ \mathbf{8}\ am \\ \mathbf{TP - Ave > 17.5\ °C} \rightarrow NV\ from\ \mathbf{12}am\ to\ \mathbf{8}\ am \end{cases} \quad (3)$$

(3) In pre-cooling strategy, cooling set-points are changed during occupancy hours. For this strategy, the set-point is changed from a lower temperature at the beginning of the day to a higher temperature in the afternoon, when the cooling load is the most.

(4) The effect of integration of different combinations of two strategies on energy savings are investigated by first, combining the strategies 1 and 3, and then combining strategies 2 and 3.

The effects of other parameters such as ventilation rates 0.24 m^3/s to 1.9 m^3/s (500-4000 CFM), temperature difference between inside and outside air 2.7°C - 11°C (5°F - 20 °F), and building thermal mass 488kg/m^2 (100 lb/ft^2) and 976.5 kg/m^2 (200 lb/ft^2) are analyzed with respect to their effects on cooling energy and peak demand.

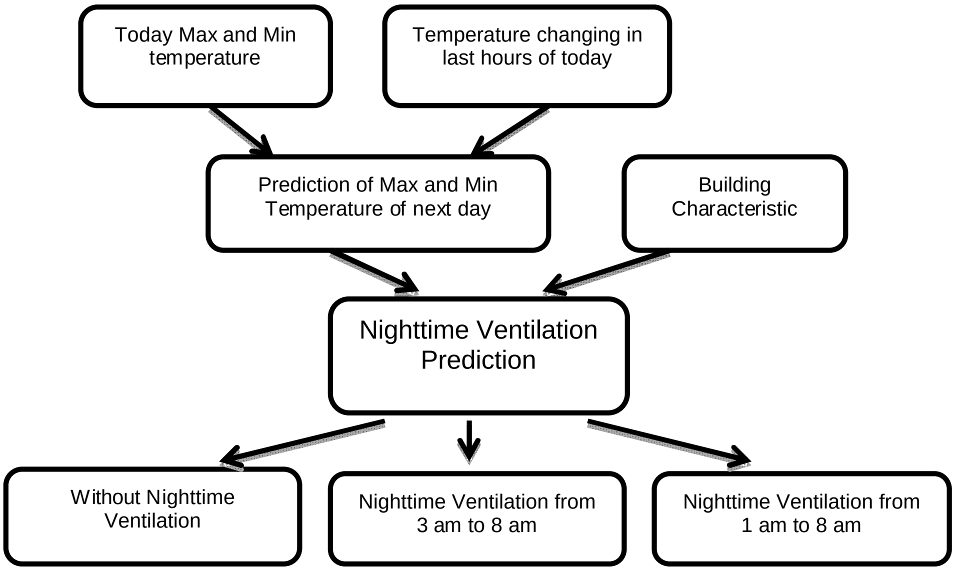


Figure 1: Control strategy diagram of the predictive method

Result and Discussion

In order to examine the effect of different parameters on the performance of nighttime ventilation, a basecase without nighttime ventilation is simulated (Table 4). Simulated cooling energy, fan energy consumption, pump and miscellaneous, heating energy consumption, total energy for cooling and ventilation, and total building energy are shown in this table. Energy use by heat rejection system (condenser fans) is also shown in this Table.

Peak cooling load in different cities is also listed in Table 4. The occupancy comfort can be investigated based on the zone under cooled hours. This parameter represents the total hours when the inside temperature of the building exceed the cooling set-point during a year.

Table 4: Simulation results for basecase in investigated cities

Parameters	Montreal	Victoria	Portland
Cooling (kWh)	5289	2520	5851
Fan (kWh)	2598	2214	2606
Heat reject (kWh)	1165	549	1245
Pump & Misc (kWh)	1197	888	1087
Reheat (kWh)	3480	1458	1087
Total cooling (Cooling + Fan + Heat reject) kWh	9052	5283	9702
Peak cooling load W/m^2 ($Btu/hr\text{-}ft^2$)	132.2 (41.91)	93.4 (29.61)	122.3 (38.77)
Zone under cooled (hours)	6	0	0

The effect of different schedules on nighttime ventilation

The effectiveness of the scheduled-driven ventilation is very sensitive to the assumption of what is the summer period. This is considered as a severe disadvantage for this strategy. In contrast, with the predictive algorithm, there is no need to pre-define a summer period schedule. This strategy automatically decides about using nighttime ventilation based on the prediction of next day temperature. The simulated cooling energy consumptions using the scheduled driven strategy with different summer period are shown in Table 5. The results show that the optimal cooling energy savings is 7.7% for the best defined summer period. While, adding two weeks to this period, savings reduces to 7.4% that is approximately equal to the amount of savings by using predictive method. The amount of savings decreases to 6.5% by adding two more weeks.

Table 5: The effect of scheduled nighttime ventilation for different periods in Montreal (DT=3°C, Flow rate= 1.4m^3/s, FW=490kg/m^2)

Parameter	Basecase	Predictive method	Scheduled ventilation during summer				
		Entire Year	1 JUN to 31 AUG	24 MAY to 7 SEP	17 MAY to 14 SEP	10 MAY to 21 SEP	1 MAY to 31 SEP
Cooling kWh	5289	4365	4397	4354	4324	4317	4298
Fan kWh	2598	2986	2915	2987	3106	3229	3376
Heat reject kWh	1165	1039	1045	1039	1031	1029	1023
Total Cooling (Cooling+ Fan + Heat reject) kWh	9052	8390	8357	8380	8461	8575	8697
Savings % (Cooling+Fan+ Heat reject)	0	7.3	7.7	7.4	6.5	5.3	3.9
Savings % (Total)	0	4.7	5	4.7	3.9	2.8	1.5
Peak cooling load W/m2 ($Btu/hr\text{-}ft^2$)	132.2 (41.91)	128.7 (40.8)	128.7 (40.8)	128.7 (40.8)	128.7 (40.8)	128.7 (40.8)	128.7 (40.8)
Zone under cooled (hours)	6	2	2	2	2	2	2

Effect of nighttime ventilation flow rate

The effect of different nighttime ventilation fan flow rates during summer with the predictive method and with the integrated pre-cooling and predictive method for Montreal and Portland are shown in Table 6. The results show that increasing fan flow rate reduces cooling energy consumption, but increases fan energy consumption. Moreover, results of the energy savings illustrate that there is fairly flat total energy consumption in the range of 1 m^3/s to 1.5 m^3/s (2200-3200 CFM) with optimal flow rate near 1.4 m^3/s (3000 CFM) (Figure 2). Simulation for Montreal shows that the savings at 1.4 m^3/s (3000 CFM) with scheduled ventilation during summer is 7.5% and with predictive method is 7%. In that, predictive method, which works during entire year, shows less savings as a result of incorrect prediction about the next day need for cooling. For Portland the simulation results has an inverse trend; savings with predictive method is higher than scheduled ventilation. The predictive nighttime ventilation worked better in Portland since its weather conditions is fairly smooth in transition seasons. Whereas, the unpredictable weather condition of Montreal makes the predictive nighttime ventilation less efficient.

With integration of pre-cooling and nighttime ventilation more energy can be saved. Whereas, hours of zone under cooled is increased using this combination method. The increased hours of under-cooled affect the occupant comfort, yet still in an acceptable range. Combined nighttime ventilation and pre-cooling reduced peak cooling load up to 20%.

Table 6: The effects of nighttime ventilation fan flow rate on scheduled ventilation during summer, predictive method, and pre-cooling integrated with predictive method for Montreal and Portland. The simulations are performed for an indoor-outdoor temperature difference (• T) of 3°C and floor weight of 490kg/m^2

Location	Parameter	Basecase	Schedule ventilation during summer				Predictive method			Pre-cooling+Nighttime cooling		
			Ventilation rate (m^3/s)				m^3/s			m^3/s		
			0.47	0.94	1.4	1.9	0.47	0.94	1.4	0.47	0.94	1.4
Montreal	Cooling kWh	5289	4845	4522	4274	4110	4829	4495	4238	4622	4332	4105
	Fan kWh	2598	2681	2848	3077	3332	2707	2903	3164	2756	2931	3180
	Total cooling (Cooling+Fan+Heat reject) kWh	9052	8633	8430	8372	8438	8641	8454	8418	8470	8318	8309
	Savings % (Cooling+ Fan+Heat reject)	0	4.6	6.9	7.5	6.8	4.5	6.6	7.0	6.4	8.1	8.2
	Peak cooling load W/m2 (Btu/hr-ft^2)	132.1 (41.9)	129.3 (41)	127.4 (40.4)	125.2 (39.7)	123.9 (39.3)	129.4 (41.03)	127.3 (40.35)	125.3 (39.72)	129.3 (40.99)	127.8 (40.53)	126.6 (40.13)
	Zone under cooled (hours)	6	2	2	1	1	2.0	2.0	1.0	24.0	19.0	17.0
Portland	Cooling kWh	5851	5367	5023	4764	4585	5268	4853	4540	4775	4433	4186
	Fan kWh	2606	2661	2824	3064	3341	2698	2916	3229	2712	2894	3160
	Total cooling (Cooling + Fan + Heat reject) kWh	9702	9199	8967	8911	8983	9126	8871	8828	8557	8355	8343
	Savings % (Cooling+ Fan+Heat reject)	0.0	5.2	7.6	8.2	7.4	5.9	8.6	9.0	11.8	13.9	14.0
	Peak cooling load W/m2 (Btu/hr-ft2)	122.2 (38.77)	117.9 (37.37)	115 (36.46)	112.4 (35.63)	110.4 (35.01)	117.9 (37.37)	115 (36.46)	112.4 (35.63)	101 (32.02)	98.6 (31.25)	97.5 (30.91)
	Zone under cooled (hours)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0

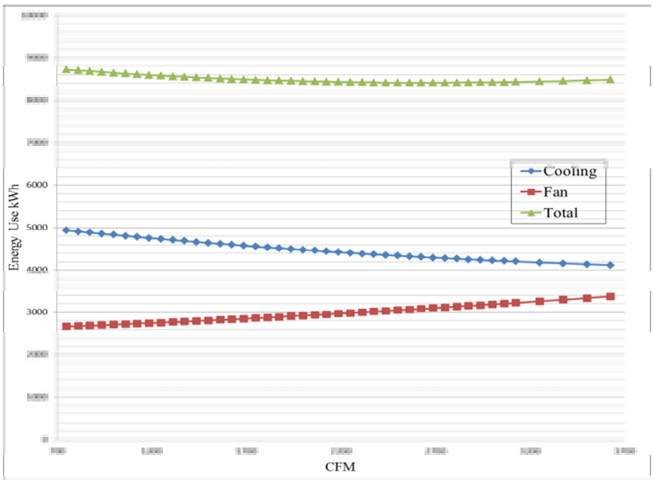


Figure 2: Energy use for Cooling, Fan and Total (cooling + fan + heat reject) with different air flow rates (CFM) in Montreal

Effect of thermal mass

Table 7 shows the effect of building thermal mass on nighttime ventilation. Here, three different floor weights with three different strategies are considered for Montreal. These strategies are without nighttime ventilation (WO NV), with scheduled ventilation during summer (W NV), and with predictive method (W FUNC). For very low thermal mass there was not any savings, as it was expected. The results show near 5% energy savings with these strategies for building medium and high thermal mass. It is possible to see that for high thermal mass, predictive method works better than scheduled ventilation during the summer.

Table 7: The effect of building thermal mass on nighttime ventilation for three different floor weights with three different strategies in Montreal (• T=3°C, Flow rate= 1.4m^3/s)

Parameter	4.9kg/m^2 (1 lb/ft^2)			490kg/m^2 (100 lb/ft^2)			980kg/m^2 (200 lb/ft^2)		
	WO NV	W NV	W FUNC	WO NV	W NV	W FUNC	WO NV	W NV	W FUNC
Total cooling (Cooling+ Fan+Heat reject) kWh	10081	10072	10142	9052	8633	8641	8811	8430	8425
Savings % (Cooling+Fan+ Heat reject)	0.0	0.1	-0.6	0.0	4.6	4.5	0.0	4.3	4.4
Peak cooling load W/m2 (Btu/hr-ft2)	122.2 (38.7)	122.2 (38.7)	124.5 (39.4)	132.2 (41.9)	130.2 (41.2)	129.4 (41.0)	125.6 (39.8)	123.9 (39.3)	123.1 (39.0)
Zone under heated (hours)	346	425	704	49	49	49	35	35	35
Zone under cooled (hours)	1	1	2	6	3	2	3	3	2

Effect of ventilation temperature difference between inside and outside air

The temperature of outside air that ventilation fan brings in during the night for cooling the building has an important effect on effectiveness of nighttime ventilation. When the temperature difference between inside and outside air is low, the brought in air is not useful in cooling the building. In this case, the ventilation fan energy use increases total energy consumption, while having little effect on cooling the building. On the other hand, if outside air is just brought in when its temperature is significantly lower from inside air, the hours of nighttime ventilation decrease and a significant amount of cooling potential that exist in outside air is not utilized. So, an optimal situation should be found between these two conditions in order to reach the maximum energy savings. Table 8 shows the building energy consumption with different temperature differences between outside and inside air for nighttime ventilation. According to these results, optimum savings for Montreal happens when the temperature difference is approximately 5.5 °C (10 °F) (see Figure 3). It is possible to see that cooling energy consumption first decreases with increasing temperature difference from 0.5 to 4.5 °C (1 to 8 °F), while this trend changes by continuing to increase the temperature difference.

Table 8: The effect of ventilation temperature difference between inside and outside air in Montreal (Flow rate= 1.4m^3/s, FW=490kg/m^2)

Parameter	Scheduled ventilation during summer			Predictive method			
	2.8°C (5.0°F)	5.5°C (10.0°F)	8.3°C (15.0°F)	2.8°C (5.0°F)	5.5°C (10.0°F)	8.3°C (15.0°F)	11.1°C (20°F)
Cooling kWh	4274	4397	4697	4238	4365	4677	4966
Fan kWh	3077	2915	2710	3164	2986	2748	2632
Total cooling (Cooling+Fan+Heat reject) kWh	8372	8357	8501	8418	8390	8515	8725
Savings % (Cooling+Fan+Heat reject)	7.5	7.7	6.1	7.0	7.3	5.9	3.6
Savings % (Total)	4.8	5.0	3.9	4.5	4.7	3.8	2.3
Peak cooling load W/m2 (Btu/hr-ft2)	125.3 (39.7)	128.6 (40.8)	131.7 (41.8)	125.3 (39.7)	128.6 (40.8)	154.5 (49.0)	132.0 (41.8)
Zone under cooled (hours)	1.0	2.0	4.0	1.0	2.0	4.0	5.0

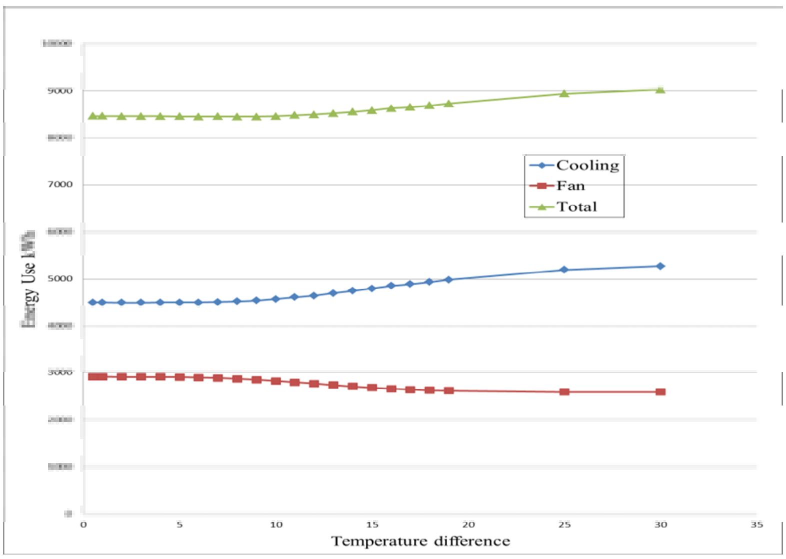


Figure 3: Energy use for Cooling, Fan and Total (cooling + fan + heat reject) for different indoor-outdoor temperature difference in Montreal

Pre-cooling

Pre-cooling is another strategy for reducing the energy consumption and specially reducing the peak load in the building. This strategy works by changing the cooling set-point during the day. In the morning, when the outside air temperature is low, the cooling set-point is set to a lower temperature than regular value. So, the building will store some cooling energy. In the afternoon, when the outside air temperature is at the highest, more cooling is required for the building. Consequently, the set-point is increased to reduce the amount of cooling energy consumption. The stored cooling energy in the building mass is then used in the afternoon. In order to find the minimum cooling energy consumption, various pairs of set-points with the same daily average were investigated. The results are illustrated in Table 10.

Table 10: Results for different Pre-cooling Methods in Portland

Parameter	Basecase	Pre-Cooling (Time)(Temp. °C) (Time)(Temp. °C)		
		(9-12)(24) (13-18)(26.6)	(9-13)(24.4) (14-18)(26.6)	(9-14)(24.7) (15-18)(26.6)
Cooling kWh	5851	5434	5264	5202
Fan kWh	2606	2653	2677	2685
Heat reject kWh	9702	9294	9070	9018
Total Cooling (Cooling+Fan +Heat reject) kWh	11952	11543	11317	11264
Savings % (Cooling+Fan+Heat reject)	0	4.2	6.5	7.1
Peak cooling load W/m2 (Btu/hr-ft2)	122.3 (38.8)	116.1 (36.8)	105.7 (33.5)	107.6 (34.1)
Zone under cooled (hours)	0	10	26	60

Effect of climate on nighttime cooling and pre-cooling

Results of the simulations for nighttime ventilation and pre-cooling show up to 15% savings for cooling and ventilation energy consumption in the three climates simulated (Table 9). Highest savings is achieved in Portland and lowest energy savings is in Montreal. Because of the unpredictable weather condition of Montreal as well as its cold weather, the scheduled ventilation strategy works better than the predictive method. On the other hand, in Portland and Victoria, the predicted ventilation strategy always leads to more energy savings. By adding pre-cooling to nighttime ventilation, energy savings increased significantly, especially when lower nighttime ventilation flow rate was used.

Table 9: Energy savings with different strategies for three different flow rates m^3/s(CFM) in investigated cities (DT=3°C, FW=490kg/m^2)

Cities	Strategy	Flow rate		
		0.47 m^3/s (1000 CFM)	0.94 m^3/s (2000 CFM)	1.4 m^3/s (3000 CFM)
Montreal	Scheduled ventilation during summer	4.6	6.9	7.5
	Predictive method	4.5	6.6	7.0
	Pre-cooling + Night-time cooling	6.4	8.1	8.2
Victoria	Scheduled ventilation during summer	6.2	7.9	6.1
	Predictive method	6.3	8.0	6.2
	Pre-cooling + Night-time cooling	11.2	11.7	9.4
Portland	Scheduled ventilation during summer	5.2	7.6	8.2

Predictive method	5.9	8.6	9.0
Pre-cooling + Night-time cooling	11.8	13.9	14.0

The effect of roof insulation

In the above simulations, the roof insulation was set at R-03 (very low insulation). In order to investigate the effect of the roof insulation on the effectiveness of the nighttime ventilation strategies, we simulated our building with different roof insulations. These simulation results (Table 10) illustrated that the higher the roof insulation the higher the energy savings (both in absolute and relative terms).

In Montreal, the scheduled ventilation resulted in more savings compared to the predictive model. As the roof insulation increases, the difference between the savings estimated by the scheduled and the predictive model strategies become less significant. For Portland and Victoria, the energy savings using predictive method became even higher than that scheduled-driven strategy.

Table 10: The effect of roof insulation in nighttime ventilation for three different cities with three different strategies in Montreal (DT=3°C, Flow rate= 1.4m^3/s, FW=490kg/m^2)

Location	Parameter	R-03			R-13			R-30		
		Basecase	Scheduled ventilation	Predictive method	Basecase	Scheduled ventilation	Predictive method	Basecase	Scheduled ventilation	Pre me
Montreal	Cooling kWh	5289	4274	4238	5032	3901	3856	5003	3811	3
	Fan kWh	2598	3077	3164	2531	2938	3016	2494	2880	2
	Heat reject	1165	1021	1016	1088	930	923	1090	906	8
	Total cooling kWh	9052	8372	8418	8651	7769	7795	8587	7597	7
	Cooling Savings kWh	0	-680	-634	0	-882	-856	0	-990	-
	Cooling Savings %	0.0	7.5	7.0	0.0	10.2	9.9	0.0	11.5	1
Portland	Cooling kWh	5851	4764	4540	5530	4362	4107	5453	4267	4
	Fan kWh	2606	3064	3229	2652	3037	3164	2678	3045	3
	Heat reject	1245	1083	1059	1154	989	966	1117	958	9
	Total cooling kWh	9702	8911	8828	9336	8388	8237	9248	8270	8
	Cooling Savings kWh	0	-791	-874	0	-948	-1099	0	-978	-1
	Cooling Savings %	0.0	8.2	9.0	0.0	10.2	11.8	0.0	10.6	1
Victoria	Cooling kWh	2520	1775	1762	2395	1603	1590	2368	1564	1
	Fan kWh	2214	2745	2750	2283	2724	2727	2332	2738	2
	Heat reject	549	443	442	503	405	404	486	394	3
	Total cooling kWh	5283	4963	4954	5181	4732	4721	5186	4696	4
	Cooling	0	-320	-329	0	-449	-460	0	-490	-

Savings kWh									
Cooling Savings %	0.0	6.1	6.2	0.0	8.7	8.9	0.0	9.4	[illegible]

Discussion and conclusions

This paper examined the effect of mechanical nighttime ventilation and pre-cooling on energy consumption in typical office buildings in northern America. Some parameters such as climatic conditions, nighttime ventilation rate, indoor-outdoor temperature difference, and thermal mass were investigated. DOE2.1E was used to evaluate the importance of different parameters on nighttime ventilation cooling. The result for different nighttime air flow rates show that, total energy consumption is fairly flat in the range of 1 m^3/s to 1.5 m^3/s with optimal flow rate near 1.5 m^3/s in the chosen building models. Also, the results illustrate that peak cooling load decrease by increasing the ventilation flow rates.

Evaluation of nighttime ventilation energy savings as a function of thermal mass in medium and high building thermal mass demonstrates near 5% energy savings in Montreal. In addition it shows that for high building thermal mass predictive method works better than scheduled ventilation during the summer. Simulations with different temperature difference between inside and outside air show when outdoor temperature is proximately 5.5 °C (10 °F) lower than indoor temperature, nighttime ventilation works well for both strategies. The results for different climate conditions show that very cold climates such as Montreal have less energy savings than hotter climates such as Portland. Based on the control strategies simulated for the office buildings in the three cities, it is found that most energy savings are achieved when the building is cooled by nighttime ventilation integrated with pre-cooling.

Acknowledgment

This work was supported by an internal grant form the Faculty of Engineering and Computer Science at Concordia University, Montreal, Canada.

References

[1] DOE-2. 2007. Lawrence Berkeley National Lab DOE-2 website. Online at

http://simulationresearch.lbl.gov/dirsoft/d2whatis.html .

[2] Kolokotroni, M., Aronis, A., 1999. *Cooling-energy reduction in air conditioned offices by using night ventilation*. Applied Energy 63 (4), 241–253.

[3] Gratia, E., Bruyere, I., De Herde, A., 2004. *How to use natural ventilation to cool narrow office buildings*. Building and Environment 39 (10), 1157–1170.

[4] Shaviv, E., Yezioro, A., Capeluto, I.G., 2001. *Thermal mass and night ventilation as passive cooling design strategy*. Renewable Energy 24 (3–4), 445–452.

[5] B. Givoni, 1991. *Performance and applicability of passive and low-energy cooling systems*. Energy and Buildings, 17 (1991) 177-199

[6] James E. Braun, 2003. *Load Control Using Building Thermal Mass*. Journal of Solar Energy Engineering Vol. 125 / 301.

[7] Stephen Morgan, Moncef Krarti, 2005. *Impact of electricity rate structures on energy cost savings of pre-cooling controls for office buildings*. Building and Environment 42 (2007) 2810–2818.

[8] Rongxin Yin , Peng Xu, Mary Ann Piette, Sila Kiliccote, 2010. *Study on Auto-DR and pre-cooling of commercial buildings with thermal mass in California*. Energy and Buildings 42 (2010) 967–975.

[9] G. Agas and T. Matsaggos, 1991. *On the use of the atmospheric heat sinks for heat dissipation*. Energy and Buildings, 17 (1991) 321-329

[10] A.N. Ayoob and J.L. Izard, 1994. *STUDY OF COMFORT IN ATRIUM DESIGN*. Renewable Energy, Vol.5, Part II, pp. 1002-1005.

[11] Givoni, B., 1998. *Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures*. Energy and Buildings 28 (1), 25–32.

[12] Pfafferott, J., Herkel, S., Jaschke, M., 2003. *Design of passive cooling by night ventilation: evaluation of a parametric model and building simulation with measurements*. Energy and Buildings, 35 (11), 1129– 1143.

[13] Artmann, N., Manz, H., Heiselberg, P., 2008. *Parameter study on performance of building cooling by night-time ventilation*. Renewable Energy 33 (12), 2589–2598.

[14] Lina Yang, Yuguo Li, *Cooling load reduction by using thermal mass and night ventilation*, Energy and Buildings 40 (2008) 2052–2058.

[15] Geros, V., Santamouris, M., Tsangrasoulis, A., Guarracino, G., 1999. *Experimental evaluation of night ventilation phenomena*. Energy and Buildings 29 (2), 141–154.

[16] Kolokotroni, M., Webb, B.C., Hayes, S.D., 1998. *Summer cooling with night ventilation for office buildings in moderate climates*. Energy and Buildings 27 (3), 231–237.

[17] Zhaojun Wang, Lingli Yi, Fusheng Gao, 2009. *Night ventilation control strategies in office buildings*. Solar Energy 83 (2009) 1902–1913.

[18] Wu Li-Xia, Zhao Jia-Ning, Wang Zhao-Jun, *Night ventilation and active cooling coupled operation for large supermarkets in cold climates*. Energy and Buildings 38 (2006) 1409–1416

[19] Finn, D., Connolly, D., Kenny, P., 2007. *Sensitivity analysis of a maritime located night ventilated library building*. Solar Energy 81 (6), 697–710.

[20] DOE-2 Supplement (Version 2.1E). 1994. Berkeley, CA, USA: Lawrence Berkeley Laboratory.

[21] Joe Huang. 2011. Private communication. yjhuang@whiteboxtechnologies.com

WINDOW FILM AND ENERGY EFFICIENCY IN BUILDINGS

Dave Cox
EWFA president

Hans Craen,
European Window Film Association (EWFA), Brussels; Belgium

Abstract:

The European Window Film Association (EWFA) is an international not-for-profit organisation founded in 2000 in Belgium to represent and further the interests of the window film industry.

Based on technical data and case studies, the presentation will set out how window film can and does play a useful and viable role in improving the energy efficiency of existing buildings, without disruption or the need to dispose of the existing glazing; a truly sustainable solution.

As many of you may not be familiar with this energy saving solution, the presentation will first look into the technology components and manufacturing processes of window film as a product. The advanced properties of window film are essential in order to explain how this product reacts with the solar spectrum.

Following this introduction, the presentation will explain in more detail how this technology can improve the energy efficiency of a wide range of buildings. This part will be explained by using data which has been gathered through various case studies and independent assessments.

One example to expand upon is the result of the retrofit of a medium sized commercial building in the Northern part of the US using the Whole Building Approach'. Through this approach, the energy consumption for the whole building before and after installing film was taken into account as well as the impact on the energy use by variations in weather and building occupancy (see figure 1).

1. Introduction

Window film is a self-adhesive optically clear thin film that is applied to glass and glazing systems of existing buildings to modify and enhance the properties of the glass without changing the window or building structure. Window films can absorb and reflect up to 80% of the heat coming from outside producing quantifiable energy savings from cooling systems or alternatively reduce heat loss from the building through the glazing system. Window films can be used on virtually any glazing type, complementing and enhancing the solar performance control of the glass.

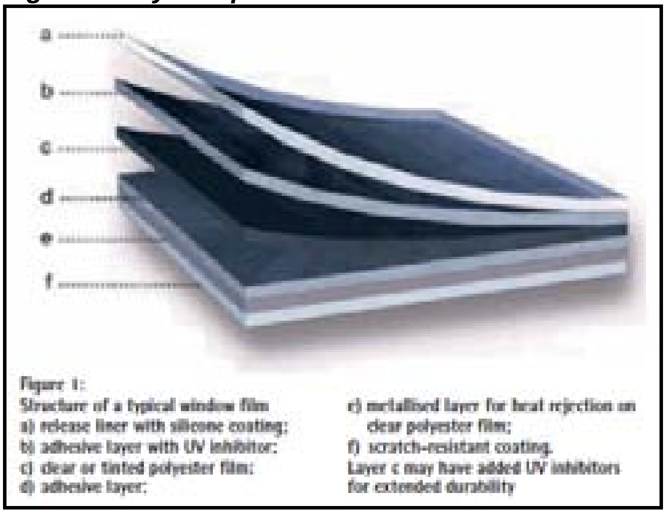
Window film technology

Various coatings and constructions with up to 230 different layers are used in some window films to create their advanced properties, making them highly effective and durable quality products; they are not simply a sticky backed plastic. The performance and durability of window films is determined by the type and quality of the components used in the film and the construction used. The essential components of window film include:

- Protective Release Liner: A film, usually polyester, which is used to cover the adhesive and protect it from contamination before installation.
- Adhesive: High quality, low or zero distortion adhesives that adheres the polyester film to glass; types used for automotive installations retain high adhesion even on double curved glass.
- Polyester Film: A strong, high clarity, high quality plastic film – more than one layer may be used with a laminating adhesive to produce a multi-layered structure.

- Scratch Resistant Coating: A hard acrylic coating that provides protection for the polyester against scratching and abrasion.
- Dyes, metals, alloys and UV inhibitors: are added to produce the specific properties desired.

Figure 1: key-components of window film



The manufacturing process requires also a high level of precision in order to ensure high quality. The different steps in this process are:

- Coating: Adhesives and scratch resistant coatings are transferred from a container to a roller and then rolled onto the surface of the polyester.
- Laminating: A film coated with adhesive is adhered to a second uncoated film, using a roller system to press the two films together.
- Metallising: Polyester film is wound round a water-cooled roller in a large metal vacuum chamber. Metal – usually aluminium – is evaporated onto the cold surface of the film.
- Sputtering: Using similar equipment, a metal or alloy target is bombarded with positive ions to knock (sputter) atoms of metal out of the target and onto the cold film surface. A larger number of different metals and alloys can be sputtered and some, such as nickel, may also have extra resistance to corrosion. Slower but more precise than metallising.
- Colouring: The colouring of window film may be achieved in several different ways. The adhesive may be coloured before coating it on the film or a laminating layer may be coloured or even the scratch resistant coating may incorporate the colour within it The use of dyes or pigments may be used to colour the actual polyester base film after it is manufactured or during the extrusion process itself. The manufacturer of any specific film would be able to explain the process used in its construction and the reasons, uses and benefits that may result.

Window film characteristics

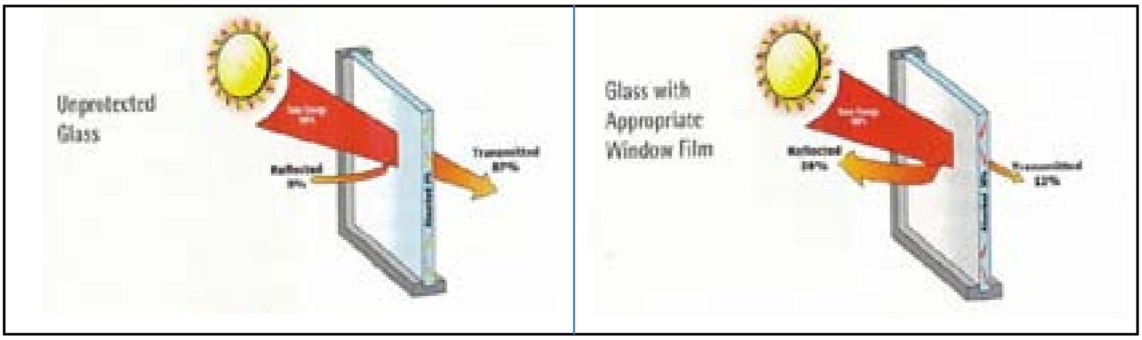
Looking at the characteristics of window film, various benefits can be identified in addition to thermal comfort and increased energy efficiency in buildings such as safety & security and overall privacy. However since these fall outside the remit of the topic, this presentation will only focus on the energy efficiency aspects of window film.

2. The impact of window film on energy efficiency

Solar control films reflect, absorb, and transmit different parts of the solar spectrum thereby controlling the appearance and performance characteristics of the glass. This includes colour, UV transmission, infrared transmission, glare, reflectivity and emissivity. As such the efficiency of energy usage and occupant comfort in buildings can be improved by reducing peak demands brought about by localised excessive heating or cooling demands.

The most typical construction is to have a very thin coating of metal applied to a thin polyester film with an optically clear and long lasting adhesive that bonds the film to the window, allowing the metal to reflect away the sun's heat and allowing you to see out. The top window is allowing 87% of total solar energy into the building and with the film this can be reduced to 12%.

Figure 2: Difference in solar energy transmission when comparing clear glass and glass with appropriate window film



By reducing excessive solar heat gain and reducing heat loss through the glazing system and by maintaining stable temperatures in buildings, window films can substantially decrease the need for energy intensive cooling and heating systems. As the number of air conditioned buildings continues to rise across Europe, the demand for energy in buildings keeps escalating. Cooling buildings appears as a growing source of this escalation of energy demand as it often consumes significantly more energy than heating.

By using modern high technology solar control window films, the cooling loads demanded by air conditioned buildings can be substantially decreased, hence achieving savings in energy costs whilst reducing CO_2 emissions. In addition, when the need to replace the cooling system arises for a building, the size of the cooling system may be reduced in addition to having a lower energy demand when operating.

In the below table is an example of the calculations taken from the software (Optics 5 and Windows 6) to calculate the effect of any type of window in any particular building.

Table 1: Software calculations to assess the effect of any type of window

Outer pane	PPG Clear Float 6 mm (5012)	PPG Clear Float 6 mm + PR70EX (30366)	PPG Clear Float 6 mm (5012)
Gap	Air 12 mm	Air 12 mm	Air 12 mm
Inner pane	PPG Clear Float 6 mm (5012)	PPG Clear Float 6 mm (5012)	PPG Clear Float 6 mm Silver20 (30365)
SC	0,808	0,447	0,379
SHGC	0,703	0,389	0,33
Rel. HG [W/m²]	532	304	260
VLT	0,791	0,629	0,155
NFRC 100-2010 Tilt 90°			

Source : 3M

Legend

Outer pane: Outer pane (NFRC ID)	**SC**: Shading coefficient
Gap: Space between two panes in double glazing (NFRC ID)	**Inner pane**: Inner pane (NFRC ID)
SHGC: Solar heat gain coefficient = g-value = transmission + to the inside emitted absorption	**VLT**: Visible light transmission
Rel. HG [W/m²]: Relative heat gain according NFRC: RHG = (Summer U-value x 7.8°C) + (Shading Coefficient x 630)	
NFRC 100-2010: Solar spectrum and tilt used for the calculation of the values mentioned above **Tilt 90°**	

The fundamental requirement is to ensure the solar control window film reflects high levels of solar radiation back to the outside, before this solar energy can be absorbed by or enter into the building. With g values of as little as ¼ that of the glass itself and total solar energy rejection values as high as 81% the solar control performance of glass can be improved considerably[1]. This shows that the range of solar control window films works well for various types of glazing. Typically, the metallised films, using aluminium, copper and silver, along with certain specific spectrally selective films have higher performances. Neutral films, using nickel or stainless steel, have more moderate performance and are more suited to clear glazing and older style buildings. External solar control films also provide high performance protection and can be used on virtually any glazing type.

In annex 1, a simulation is given of external film on solar control glazing to prove that even on that glass a significant improvement of the g-value can be achieved.

Case study[2]

The following is an example of actual results of a retrofit of a medium size commercial building in the Northern part of the USA using the “Whole Building Approach” and was carried out by an independent Energy Services Company. The whole building approach uses the energy consumption for the whole building before and after installing film and takes into account the effect on the energy use by variations in weather and building occupancy. In both the years before the film application and following the film application, no other energy saving measures were undertaken so that the energy savings could be attributed to the film alone.

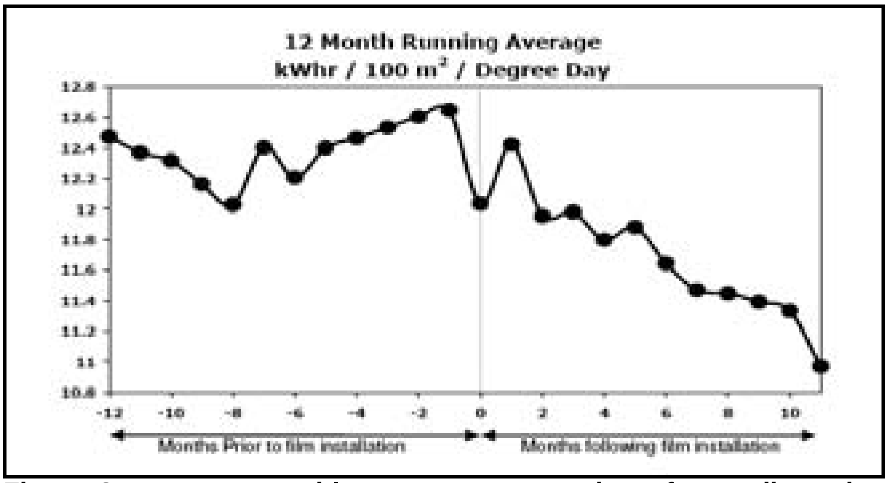


Figure 3: average monthly energy consumption of a medium sized building before & after window film (Source: CP Films)

[1] In the presentation, we will show some glazing simulations from 2/3 glass types with and without films

[2] We are developing further examples on how the Public Private Partnership approach is being used to great effect with the League of Green Embassies along with the EE Global/Alliance to Save Energy endorsement. Leed accreditation in the US and opinion on Eco Labelling/Cost Optimality and emphasizing that the focus should not be on U Values exclusively but to include G values as a vital part of being able to help Member States to meet their targets.

The following table summarises the main outcome of this project and underlines the positive and beneficial impacts window film has on the overall energy consumption.

Table 2 : Summary of the positive and beneficial impacts window film has on the overall energy consumption.

Actual savings	
Without energy control film	2 153 000kWHr
With energy control film	1 963 540 kWHr
Energy savings	189 460 kWH = 8,8%
Simple payback	2,65 years

At this moment, every Member State is establishing its own criteria to help fund energy efficient products. As an example, the Green Deal in the UK allows funding of energy efficient products if the payback time falls within the warranty. As the payback time of window film is between 2 – 6 years (subject to the film) and the warranty in general is 10 years, it is recommended that window film should be included as an approved energy efficient product.

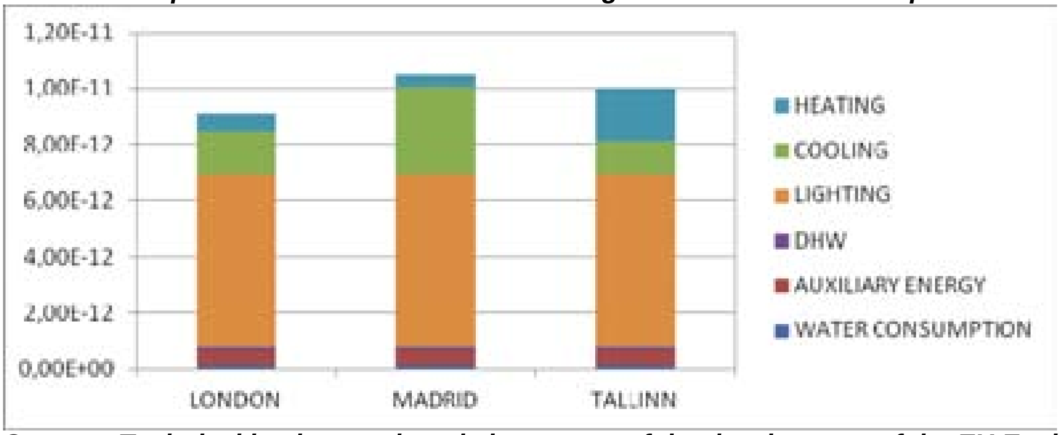
3. Conclusion

The building sector accounts for 40% of the EU's energy consumption and offers the largest single energy savings potential. In addition the existing building inventory far outweighs newly constructed buildings in any given year or period of years so the potential for energy reduction is far greater for retrofitting than merely increasing stringency on requirements for newly constructed buildings.

Cost effective energy saving technologies are therefore more sought after than ever and window film provides a low cost and highly effective solution. Window film can be applied in existing buildings to enhance the properties of the glass. By reducing excessive heat gain or loss through the glazing system and maintaining stable temperatures, window films can substantially decrease the need for energy intensive cooling and heating.

Table 3, which comes from a European Commission study on eco-labels for buildings, shows the importance cooling has in the entire building envelope.

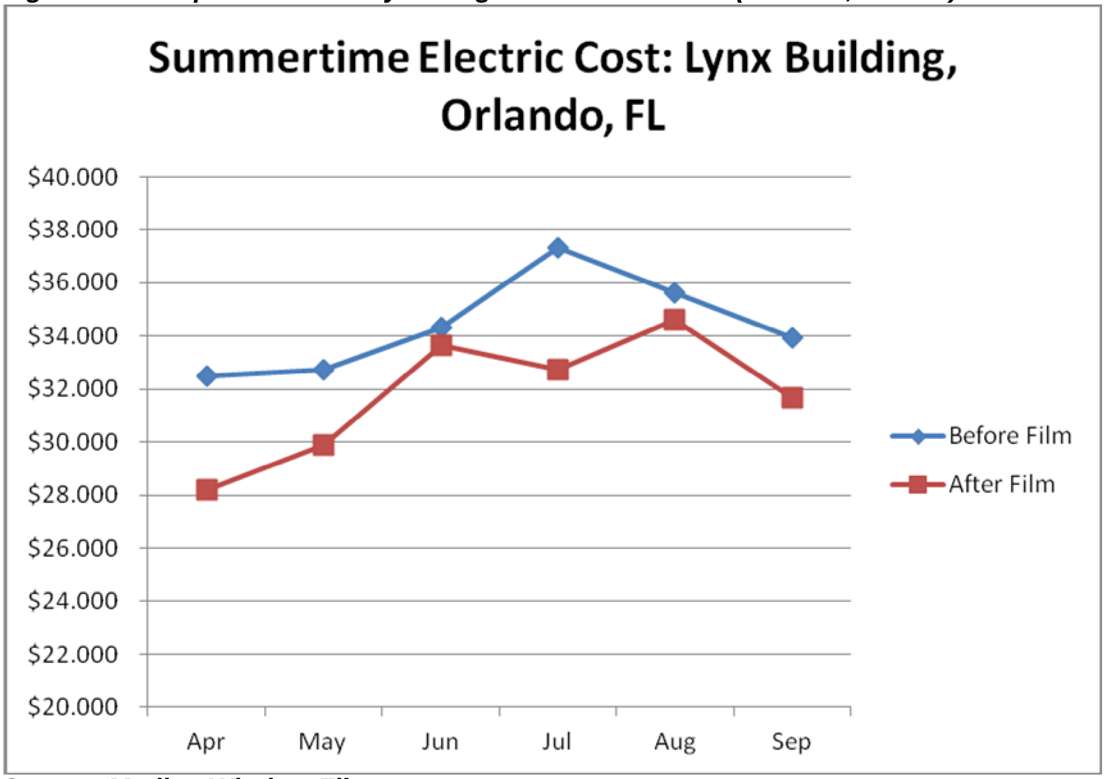
Table 3: Comparison of the normalised and weighted results of the use phase for each location



Source: Technical background study in support of the development of the EU Ecolabel and GPP criteria for office buildings

The following table shows the electricity savings that can be done when applying window film on a building. This particular example relates to a US government building in Orlando, Florida. For this building, it is anticipated that the film will result in a $2^{1/2}$ year payback time and a projected reduction in CO_2 emissions of 137 tonnes per year.

Figure 4: Example of Electricity savings with window film (Orlando, Florida)



Source: Madico Window Films

As this highly effective solution allows significant enhancement of existing glazing, there is often no need to replace them, making it a very sustainable option. In addition, the component can typically be installed without causing any disruption to the normal functioning of the building. This makes the use and energy saving benefits of the technology more accessible and affordable to all.

Retrofitting of glazing through window film technology is therefore an extremely energy-efficient and cost-effective solution to improve the overall energy performance of existing buildings thereby contributing to the energy reduction called for by the European energy efficiency discussions.

4. Sources

- European Window Film Association, *Just Look,* June 2008. http://www.ewfa.org/sites/default/files/ewfa_mag_050608.pdf
- IRCE, *Technical background study in support of the development of the EU ecolabel and GPP criteria for office buildings – Development of European Ecolabel and Green Public Procurement Criteria for Office Buildings JRC IPTS Draft Preliminary Study,* October 2011.
- Madico Window Films, *LYNX Case Study*. October 2011.
- 3M technical data - Lawrence Barkely University evaluated
- Hanita Coatings technical data - Lawrence Barkely University evaluated
- NFRC: National Fenestration Rating Council

Annex I (source Hanita Coatings)

1) Glazing System Thermal and Optical Properties (Glass & no film)

Characteristics			
Tilt	90.0	**SHGCc**	0.33
Glazings	2	**SCc**	0.38
KEFF	0.0297	**Vtc**	0.51
Width	24.110	**RHG**	252.26
U-value	1.63		

Environmental Conditions: 1 NFRC 100-2001

	Tout (C)	Tin (C)	WndSpd (m/s)	Wnd Dir (W/m2)	Solar (C)	Tsky	Esky
Uvalue	-18.0	21.0	5.50	Windward	0.0	-18.0	1.00
Solar	32.0	24.0	2.80	Windward	783.0	32.0	1.00

Optical Properties for Glazing System

Angle	0	10	20	30	40	50	60	70	80	90	Hemis
Vtc	0.513	0.516	0.508	0.499	0.487	0.464	0.411	0.308	0.152	0.000	0.432
Rf	0.414	0.409	0.407	0.409	0.417	0.432	0.461	0.529	0.684	0.999	0.448
Rb	0.395	0.391	0.390	0.392	0.399	0.415	0.450	0.534	0.709	1.000	0.436
Tsol	0.283	0.284	0.280	0.274	0.266	0.252	0.223	0.166	0.080	0.000	0.236
Rf	0.474	0.469	0.468	0.470	0.476	0.488	0.511	0.567	0.705	0.999	0.500
Rb	0.413	0.410	0.407	0.405	0.404	0.409	0.427	0.484	0.625	1.000	0.427
Abs1	0.203	0.205	0.211	0.215	0.215	0.217	0.225	0.230	0.188	0.001	0.213
Abs2	0.041	0.041	0.041	0.042	0.042	0.043	0.042	0.037	0.027	0.000	0.040
SHGCc	0.331	0.333	0.329	0.324	0.317	0.304	0.274	0.214	0.116	0.000	0.285
Tdw-K	0.279										
Tdw-ISO	0.404										
Tuv	0.211										

:

Temperature Distribution (degrees C)

	Winter		Summer	
	Out	**In**	**Out**	**In**
Lay1	-15.8	-15.4	38.8	39.1
Lay2	11.7	12.1	30.9	30.7

2) Glazing System Thermal and Optical Properties (Glass plus silver 20 extra)

Characteristics			
Tilt	90.0	**SHGCc**	0.10
Glazings	2	**SCc**	0.11
KEFF	0.0297	**Vtc**	0.13
Width	24.156	**RHG**	84.11
U-value	1.63		

Glass and Gas Data for Glazing System

Environmental Conditions: 1 NFRC 100-2001

	Tout (C)	Tin (C)	WndSpd (m/s)	Wnd Dir (W/m2)	Solar (C)	Tsky	Esky
Uvalue	-18.0	21.0	5.50	Windward	0.0	-18.0	1.00
Solar	32.0	24.0	2.80	Windward	783.0	32.0	1.00

Optical Properties for Glazing System

Angle	0	10	20	30	40	50	60	70	80	90	Hemis
Vtc	0.134	0.135	0.133	0.130	0.127	0.122	0.109	0.084	0.044	0.000	0.114
Rf	0.627	0.624	0.623	0.625	0.629	0.636	0.651	0.688	0.784	1.000	0.641
Rb	0.593	0.590	0.589	0.589	0.593	0.600	0.618	0.665	0.773	1.000	0.610
Tsol	0.069	0.069	0.068	0.067	0.065	0.062	0.055	0.042	0.021	0.000	0.058
Rf	0.638	0.635	0.634	0.635	0.639	0.646	0.660	0.695	0.789	1.000	0.651
Rb	0.428	0.425	0.422	0.420	0.420	0.425	0.443	0.497	0.633	1.000	0.442
Abs1	0.285	0.287	0.289	0.289	0.286	0.282	0.276	0.255	0.184	0.000	0.272
Abs2	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.008	0.006	0.000	0.009
SHGCc	0.099	0.100	0.099	0.098	0.096	0.092	0.085	0.069	0.040	0.000	0.087
Tdw-K	0.053										
Tdw-ISO	0.104										
Tuv	0.000										

Temperature Distribution (degrees C)

	Winter		Summer	
	Out	**In**	**Out**	**In**
Lay1	-15.8	-15.4	41.4	41.9
Lay2	11.7	12.1	29.0	29.0

Glazing System Thermal and Optical Properties: (Glass + silver 35 extra)

Characteristics			
Tilt	90.0	**SHGCc**	0.18
Glazings	2	**SCc**	0.20
KEFF	0.0297	**Vtc**	0.25
Width	24.156	**RHG**	139.97
U-value	1.63		

Environmental Conditions: 1 NFRC 100-2001

	Tout (C)	Tin (C)	WndSpd (m/s)	Wnd Dir (W/m2)	Solar (C)	Tsky	Esky
Uvalue	-18.0	21.0	5.50	Windward	0.0	-18.0	1.00
Solar	32.0	24.0	2.80	Windward	783.0	32.0	1.00

Optical Properties for Glazing System

Angle	0	10	20	30	40	50	60	70	80	90	Hemis
Vtc	0.246	0.248	0.244	0.240	0.234	0.223	0.199	0.151	0.076	0.000	0.209
Rf	0.446	0.442	0.440	0.442	0.449	0.460	0.482	0.539	0.682	0.999	0.473
Rb	0.475	0.471	0.470	0.471	0.477	0.489	0.517	0.585	0.733	1.000	0.505
Tsol	0.130	0.131	0.129	0.126	0.123	0.116	0.103	0.077	0.037	0.000	0.109
Rf	0.465	0.461	0.460	0.462	0.468	0.479	0.499	0.552	0.690	0.999	0.490
Rb	0.377	0.373	0.371	0.369	0.371	0.378	0.401	0.464	0.618	1.000	0.398
Abs1	0.387	0.391	0.393	0.394	0.391	0.387	0.380	0.355	0.261	0.001	0.374
Abs2	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.016	0.011	0.000	0.017
SHGCc	0.176	0.177	0.175	0.173	0.170	0.163	0.148	0.119	0.068	0.000	0.153
Tdw-K	0.091										
Tdw-ISO	0.184										
Tuv	0.000										

Temperature Distribution (degrees C)

	Winter		Summer	
	Out	**In**	**Out**	**In**
Lay1	-15.8	-15.4	45.1	45.9
Lay2	11.8	12.1	30.8	30.5

Comparison of Thermal Plants for the Energy Retrofit of a Building Block

L. C. Tagliabue, M. Maistrello

Department of Building Environment Science & Technology, Politecnico di Milano, Milano, (Italy)

Abstract

The Directive EPBD recast in 2010 states that buildings in the public sector have to become nearly zero energy in the next years. To reach this task is important to reduce energy consumption in buildings working on envelope thermal performance and efficiency of thermal plants. Heat pumps are suggested by the Directive as means to produce thermal energy whenever it is economically advantageous. Hence, it is fundamental understand when is convenient to use this kind of systems comparing energy performance and economical feasibility, taking into account the cost of energy produced. Geothermal heat pumps (GHP), using ground as thermal source in summer and winter period, can produce huge amount of energy and economical advantages for heating and cooling of commercial and residential buildings compared with conventional systems. It must be underlined that the higher investment cost of GSHP systems leads to a relevant energy saving in short term and economical reduction of management costs in long term period. The case study presented in this work is a building block in Milan, Italy, where an important renovation took place and GSHP and EGS were analyzed as the heating and cooling alternative to standard technological solutions. In this study different plants are compared and the economical feasibility and profitability is quantified. Moreover, advanced heat pumps can obtain a zero impact on term of CO_2 emissions. The objective of this study is to show the cost-effectiveness of different systems to provide energy to a building block of about 60.000 m³.

1. Nomenclature

ESCO	= energy Service Company	CHP	= combined heating & power
NRE	= new & renewable energy	CCHP	= combined heating and cooling power
GHP	= geothermal heat pumps	ASHP	= air-source heat pump
GWHP	= ground water heat pump	COP	= heating coefficient of performance
GSHP	= ground source heat pump	EER	= cooling coefficient of performance
PV	= photovoltaic plant	DHW	= domestic hot water
CB	=condensing boiler	AHU	= air handling unit
AC	= air chiller	HVAC	= heating ventilation & air conditioning
AHU	= air handling unit	EGS	= Enhanced Geothermal System

2. Introduction

Recasting Energy Performance of Buildings Directive (EPBD) [1], European Union is promoting the improvement of buildings energy performance considering cost-effectiveness of technological solutions that have to be assessed in time step during the period of application of such Directive. The declared objectives are to increase “nearly zero-energy” buildings reducing both energy consumption and carbon dioxide emissions of 20% and increase use of RES of 20% in 2020. It seems to be an ambitious result but technologies are matures. “Nearly zero energy” building is not the same of “zero carbon” buildings but the second goal can be achieved easier after achieving the first. The reduced amounts of energy required by a nearly zero energy building may be fulfilled by systems using NRE; in this way is possible to reduce CO_2 emissions in the atmosphere, because all energy required can be fulfilled without burning any kind of fuel, not locally neither in the whole energy grid. The Directive introduces the issue that existing, new and renovated buildings should meet minimum energy performance ensuring that heating and cooling energy needs are reduced to cost-optimal levels. In

Italy, heat pumps systems are considered NRE since Law 10/91 [2] and confirmed in the national law DL 192/05 [3] “Energy efficiency in building” and subsequent updated (DL 311/06, DPR 59/09) [4] [5].

Typically the cost to install a GSHP system is greater than conventional systems, but they guarantee low running cost for buildings and provide reliable and environmentally friendly heating and cooling. In Lombardy Region it was recently compiled a geothermal energy map [6] to implement the exploitation of such a promising technology.

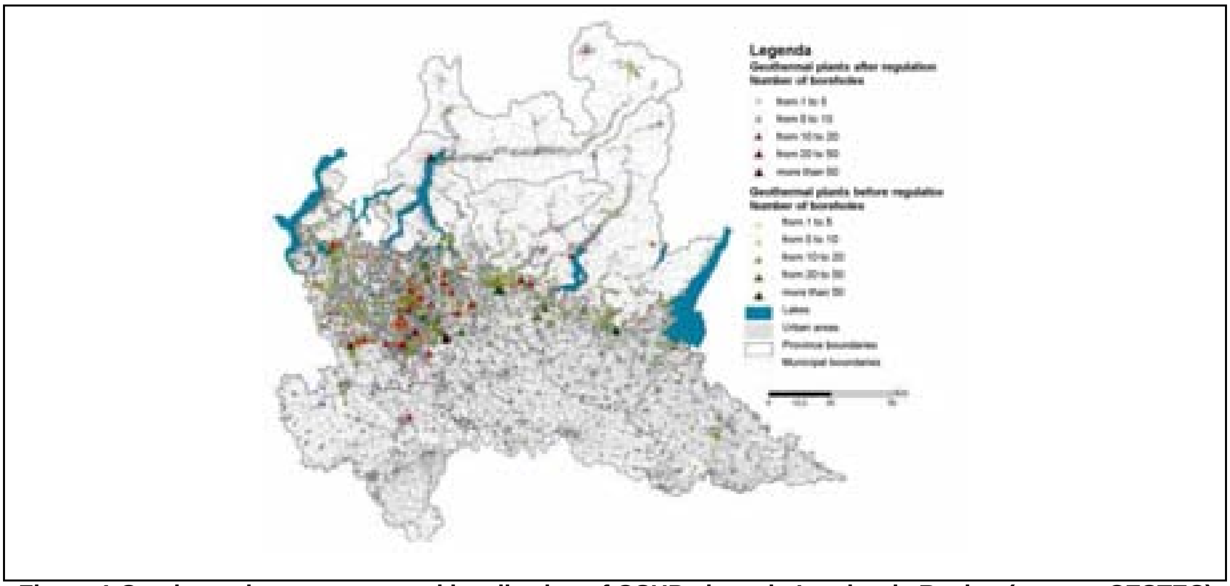


Figure 1 Geothermal energy map and localization of GSHP plants in Lombardy Region (source: CESTEC).

The 2020 projections foresee a composition of the energy mix by NRE made of a quite huge percentage by photovoltaic technologies (19%) and heat pumps (11%), with major potential represented by thermal NRE, where heat pumps will have the most important increase by 2020 [7]. In March 2011, 460 GSHP systems were registered with a total thermal power of 6500 kW_{th}.

3. Use and potential of Geothermal Systems

3.1 Ground Source Heat pump

Use of heat pumps in buildings is more focused on new buildings (65%) in comparison with renovations (35%) with a major part constituted by “small” plants (power < 50 kW_{th}) in the 77% of the cases and 23% made by “big” plants (power > 50 kW_{th}). In the building sector residential is the one in which installing GSHP is the most relevant with 93% of “small” systems and 79% of “big” systems. Commercial buildings represent between 6 and 12% in the two categories although the cooling needs of these buildings should suggest an intensive use of GSHPs. The higher percentage of “big” plants is definitely to be ascribed to commercial buildings. Other interesting data are related to the typologies of GSHP plants diffused in the territory in which is located the project of this study. The most diffused plants have a maximum of 5 ground heat exchangers with an average depth of boreholes between 80 and 100 m.

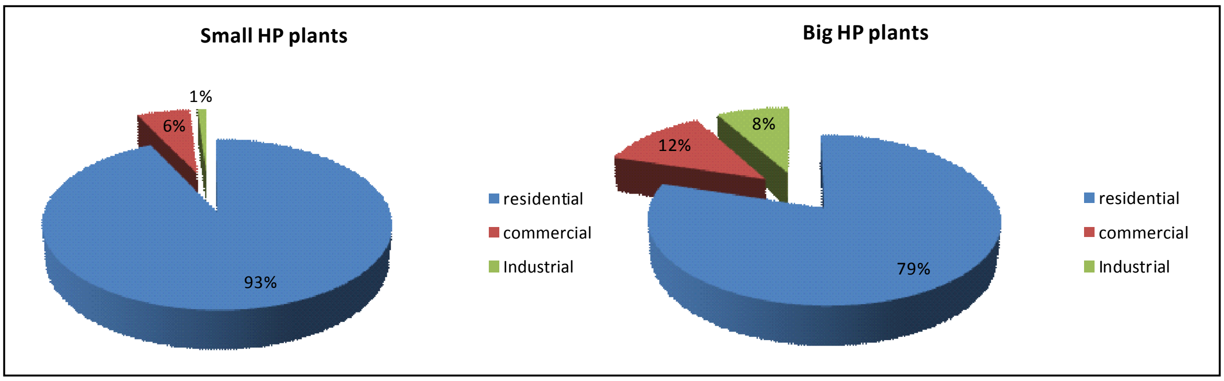


Figure 2 Distribution of "small" plants (< 50 kW_{th}) and "big" plants (> 50 kW_{th}).

The most diffused GSHP plants in the territory present 1 to 5 heat exchanger (63%), then we can find plants equipped by 6 to 10 heat exchangers (18%) and from 11 to 20 heat exchangers (14%); just a 5% of the plants have more than 20 heat exchangers. The depth of boreholes is in the 54% of the cases from 80 to 100 m; 19% of the plants have boreholes with a deepness of 80 m and quite the same number from 100 to 120 m; a 9% have more deep boreholes although the costs become very relevant.

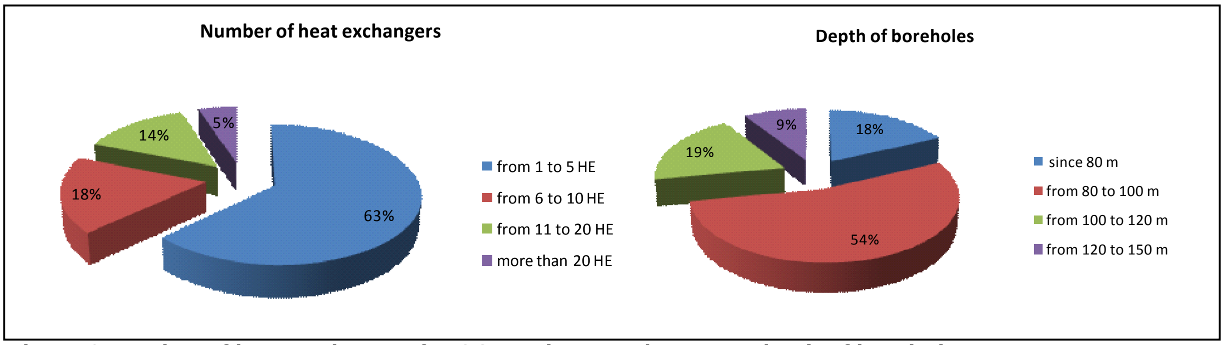


Figure 3 Number of heat exchanger for GSHP plants and average depth of boreholes.

More than the 50% of the GSHP plants installed in the territory investigated in this study provide to space heating, cooling and DHW production; a 30% of the total number of the plants is used just for space heating and DHW production and 9% it is dedicated to space conditioning. A few plants are designated to supply energy just for one sector of energy consumption.

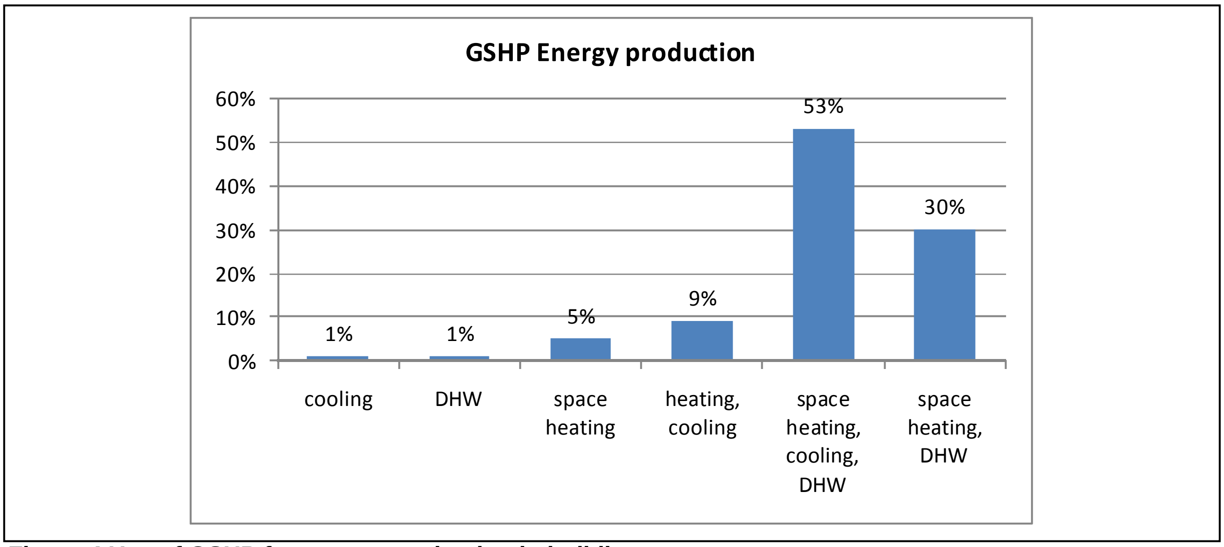
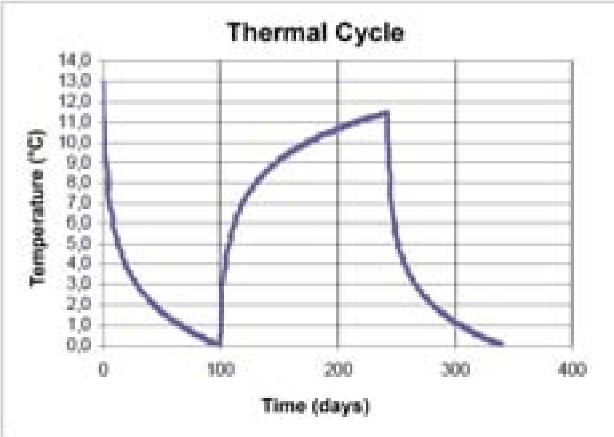


Figure 4 Use of GSHP for energy production in buildings.

GSHPs extract heat from the ground or groundwater at a relatively constant temperature (between 13 and 15°C) all times of the year in the area considered, mainly due to an high underwater flow rate in the whole Milan area. For that reason they have a higher coefficient of performance compared to ASHP. These systems can be however convenient in specific climate conditions. The GSHP system mainly comprises a heat pump, ground heat exchanger, and an internal heat distribution system. These components affect the efficiency of a GSHP system, the coefficient of performance (COP, EER) [8]. Average value in winter season (COP) can be considered >4,5 for a GWHP, while >4 for an GSHP and almost 3 for an ASHP; in summer, due to constant underground temperature of 15°C, EER can reach 6,5 for a GWHP, 5,5 for a GSHP and almost 2,9 for an ASHP.

The thermal response of a vertical borehole must be considered not only as a static response, but as a dynamic system. In Figure 5, a constant thermal flow for 100 days followed by period of time required to restore initial conditions (on/off cycle) generates a typical temperature response of the return water flowing in the borehole and therefore a variable maximum thermal flow achievable from the terrain considering as null the underground underwater flow rate. This is the result of the simulation lasted one year with constant thermal heat flow rate in three different underground conditions: high groundwater flow rate, medium groundwater flow rate and null groundwater flow rate. The lower the temperature, less power it will be obtainable from the heat pump connected, because



the COP, which is a function of the evaporating temperature, will obviously decrease.

Figure 5 Diagram of the thermal cycle and different kind of ground heat exchangers.

Characteristics of soil also affect thermal performance of the heat pump. Table 1 shows some standard value provide from CNR [9]. In general terms, different soils would act differently and will allow different peak power obtainable. In the following chart, is shown the average power per linear meter of borehole considering more than 2000 h yearly utilization.

Table 1 Soil conductivity and power to extract from different kind of soils.

Soil	Conductivity of soil [W/mK]	Power to extract [W/m]
subsoil of poor quality	Less than 1.5	20
wet rocks or waterlogged	1.5 to 3.0	50
rocks consistent high thermal conductivity	More than 3.0	70
dry sand, gravel	0.4	Less than 20
gravel, sand aquifer	1.8 to 2.4	55 to 65
wet clay, silt	1.7	30 to 40
massive limestone	2.8	45 to 60
sandstone	2.3	55 to 65
granite	3.4	55 to 70
basalt	1.7	35 to 55
gneiss	2.9	60 to 70

3.2 Enhanced Geothermal Systems

EGS are engineered reservoirs created to produce energy from geothermal resources that are otherwise not economical due to a lack of fluid and/or permeability.

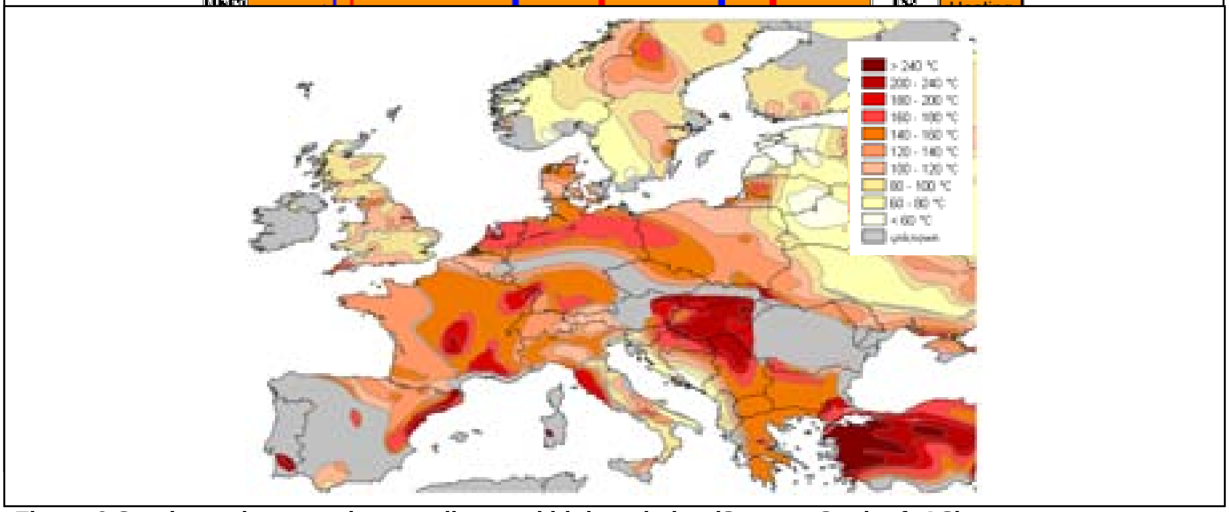


Figure 6 Geothermal source: low, medium and high enthalpy (Source: Geokraft AS).

Figure 7 Map of temperatures at 5000 m depth for Hot Dry Rock Geothermal Power Technology (BESTEC 2004).

EGSs have the potential for accessing the Earth's vast resources of heat located at depth (3-10 km) to help meet the energy needs of countries. A study of MIT for DOE (U.S. Department of Energy) estimates 500.000 MW_e of EGS geothermal resources potential lies beneath the western United States and the diffusion of technology scenario proposed identify a potential of 10.000 MW_e after 50 years, as shown in figure 8 [10]. Geothermal source plants have no expiration date. There are some geothermal plants there are still in production after 100 years of continuous production since the heat is continuously generate in the earth by the decay of radioactive elements and tidal forces.

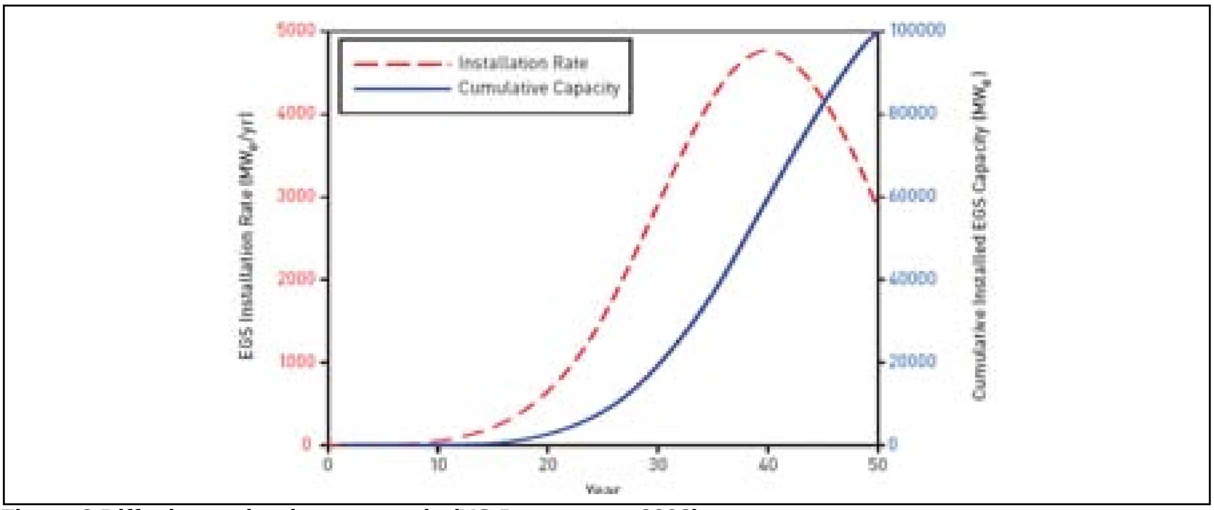
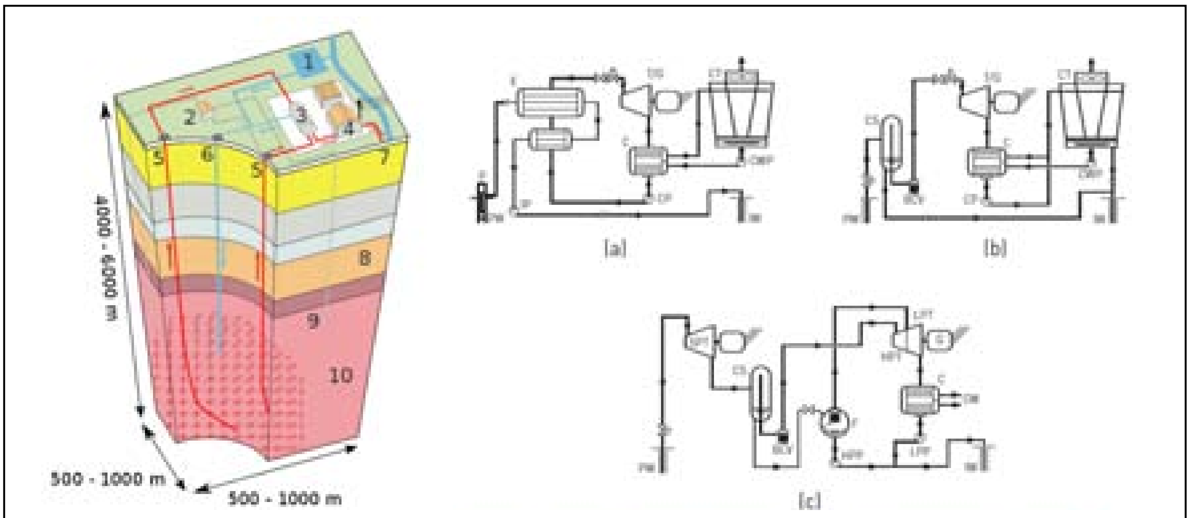


Figure 8 Diffusion technology scenario (US Department 2008).

This is approximately half of the current installed electric power generating capacity in the United States. EGS technology can enhance existing geothermal systems and create new systems where appropriate thermal and geologic characteristics occur. Characteristics of these Geothermal Systems are high-temperature rock, fluid saturation and sufficient permeability to allow geothermal fluid to flow throughout the system. During the process of creating an EGS reservoir, rocks may slip along pre-existing fractures, which may produce micro-seismic events. Induced seismicity, which can result from stimulation, helps to identify the extent of the fracture network in the reservoir. In almost all cases, these events in the deep reservoir are of such low magnitude that they are not felt at the surface

(Richter magnitude less than 2). The MIT study assumed that the principal means of EGS reservoir creation is hydraulic stimulation or the pumping of large volumes of fluids into the reservoir rock thereby fracturing the rock or opening pre-existing fractures. Hydraulic stimulation is a standard, mature technology [11], used in oil and gas fields to enhance production. This technology has been applied at all the EGS field projects to date with varied success. The MIT study contains an excellent summary of those stimulation experiments. The key assumption associated with reservoir creation is that sufficient volumes of rock can be stimulated with enough fracture surface area and permeability to enable the extraction of large quantities of heat. This assumption is partially corroborated by EGS field experiments around the world, notably at Soultz-sous-Forêts, France. Rock volumes on the order of cubic kilometers can be stimulated, assuming that observed micro-seismic events are indicators of shear fractures and hence, correlate with reservoir volume. However, the assumption that the reservoir volume has adequate interconnectivity or permeability at commercial scales has not yet been proven. The results to date are based on pilot-scale experiments. An attempt to expand the reservoir at Soultz by connecting a third well to two others was largely unsuccessful, probably due to a previously unknown permeability barrier within the reservoir [12]. Assumptions about the ability to create EGS reservoirs of sufficient volume, surface area, permeability, and inter-well connectivity for commercial applications are reasonable, but optimistic, given the current state of knowledge. These assumptions have not been corroborated by large, well-documented field projects in a number of different geologic settings. However, benefits of EGS are indubitable. Most power plants use a closed-loop binary cycle and will have no greenhouse gas emissions other than vapour from water



that may be used for cooling. EGS has enormous potential to be an important contributor to energy portfolio as a source of clean and renewable energy. EGS will increase energy production by producing geothermal energy in new environments and at various depths. Geothermal energy has the ability to produce energy consistently and around the clock. EGS has the potential to create high-paying, long-term jobs.

Figure 9 Schematics of EGS power conversion systems: (a) a basic binary power plant; (b) a single-flash power plant; (c) a triple-expansion power plant for supercritical EGS fluids [13].

4. Case study

Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance. The objective of this study is to present the results of the analysis on energetic, environmental and economical advantages due to different plants than focusing on the most promising: the synergy of a GSHP system that use NREs coupled (GSHP+PV) in comparison to a conventional one made by a condensing boiler and an air chiller (CB+AC), a cogenerating system (CCHP) and an enhanced geothermal system (EGS), evaluating market conditions and lifetime. Typical cost of electrical energy in Italy is 0.15 €/kWh, and typical cost 0.07 €/kWh using natural gas condensing boiler and can reach 0.15 €/kWh using gas oil.

4.1 Settlement specifications

The building block considered needs generation of heating and cooling during all the year for a building complex of 58.536 m^3 made by six buildings with mixed use, located in Milan, Italy (Latitude 45°; Degree days 2404; maximum summer temperature 31.9°C; winter project temperature -5°C; Average sum of global irradiation 1270 kWh/m2 year).

The building block was subjected to renovation in 2010. Energy consumption of the building block amounted to 586 MWh/year of electricity, 4900 MWh/year of thermal energy for heating and 2500 MWh/year for cooling. After the renovation all the buildings must have a minimum energy performance in accordance with the national law, therefore the focus is how to supply energy in the more efficient and cost effective manner. The complex, located in the south-east of Milan, (Italy), consists of six building named with alphabetical letters A,B,C,D,E,F with mixed uses. Buildings A,F,D, are residential buildings (university residence) and buildings B,E can be assimilated to schools; C is a commercial building. Some buildings are new or recently renovated, as shown in table 2, complying local regulation on heating primary energy [14]. Buildings characteristics are resumed in table 2.

Table 2 Characteristics of the buildings of the settlement

Building	Volume [m^3]	Use	New/Renovated
A	9970	residential	New
B	8242	classrooms	Renovated
C	13.791	commercial building	Renovated
D	6774	residential	Renovated
E	13.286	classrooms	Renovated
F	6473	residential	Renovated

Building B system scheme is shown as an example of the planned solutions in figure 11.

Figure 10 Plan of the building block with indication of the buildings of the previous table.

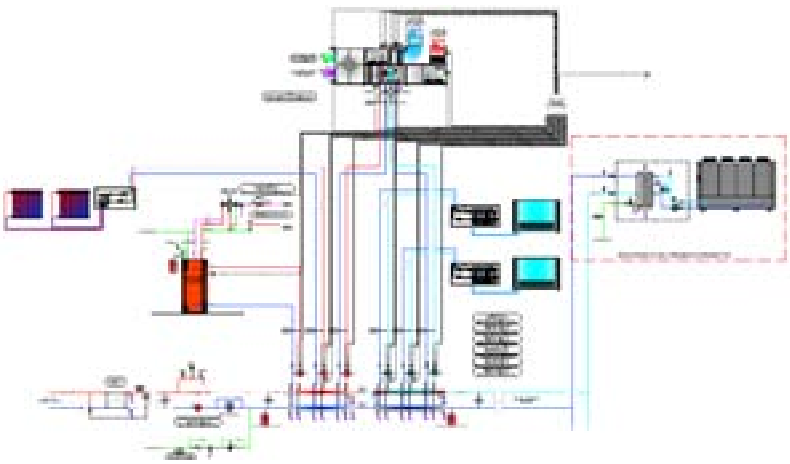


Figure 11 HVAC system building scheme of Building B.

4.2 HVAC system specifications

Buildings internal distribution piping includes different typologies, all capable to be fed with water in winter period at temperature between 50 and 60°C, as required by law, and in summer period at temperature of 7°C (supply) and 12°C (return) for air conditioning purposes. The renovation includes also the installation of heat exchangers for the six buildings substations. The main plant typology is a 4 pipes circuit equipped with heat exchangers for every substation. These substations are connected to a thermal plant, set up as described below, that provides cool and hot water through an external piping to the substation of the different buildings, similar to district heating layout. It consists in a modified four pipes layout. The first circuit is feed by water at temperature of 65°C and return of 55°C mainly designed to produce hot water and to feed the post-heating batteries of AHU. The second is fed in winter period by hot water at temperature of 50°C and return at 45°C and in summer period by cold water at temperature of 7°C and return at 12°C to feed fan-coils. DHW is produced locally, only in the residential buildings, using boilers that receive heat required from the hot water pipes; the same used the post-heating batteries of AHU. The classroom and commercial buildings (B,D,E) require in summer period cool water from the central cooling plant for room temperature control and dehumidification. The energy required to comply such a task is high and of the same magnitude of the energy required in the winter period for all the buildings. The most restrictive condition occurs during winter period, in which 1 MW of thermal power is required by the whole settlement, including DHW and space heating, when the external temperature reaches the lowest design value for Milan (-5°C). The residential buildings (A,D,F) have no connection with the central cooling plant and therefore no energy is required for temperature control in the summer period. In summer the requirement is less restrictive and the cooling plant power doesn't exceed 700 kW. Therefore, seven different solutions have been analyzed to accomplish this task and the study takes into account the different performance of each system.

5. Methodology

3.1 Analysis themes

The analysis carried out in this study uses a methodology of four evaluation steps related to energy, economical and environmental aspects of the thermal and electric energy supply systems, in detail:

- Identification of different systems to supply energy to buildings block in terms of thermal and electrical energy (produced and used).
- Evaluation of the systems to supply energy in term of net primary energy and cost of the energy produced.
- Environmental evaluation for the plant solutions to estimate the environmental impact in term of CO_2 emissions;
- Cash flow analysis for the best plant solutions in a lifespan of 25 years.

The study considers the point of view of an ESCO managing the energy supply for the buildings block with the need of economic return and a payback time of the investment compatible to the business plan. The cost of energy from the different energy plants solutions are calculated in the hypothesis that the system chosen should give, at least, a minimal annual positive balance. Comparison is made on economic tariff of the thermal MWh provided in summer and winter period estimated as the annual balance related to the total amount of energy required. This tariff includes the initial investment cost, maintenance and the other running costs of each solution analyzed in a 25 years lifetime. Costs of electrical and thermal energy are considered based on rates currently adopted [15].

3.3 Plant specifications

To estimate the most cost-effective system to provide thermal energy during the year, seven case studies of different thermal plants have been taken into account in the analysis, and are synthetically described below:

CCHP+GSHP: in this case the natural gas-fired plant designed for the settlement is a CHP plant (electric power 150 kW), matched with absorption chillers (100 kW) and a dual GSHP (1000 kW) made by a ground exchanger capable to handle at least the 75% of thermal annual load and the remaining 25% dissipated by an air heat exchanger. This choice as been made to avoid degradation of performance of the system due to air heat exchanger but to maintain the costs, that are mainly influenced by the ground heat exchanger, at an acceptable level. This system uses electrical power to perform these tasks from the electrical grid. CHP plant provides an equivalent amount of electrical energy that the GSHP uses and it recovers the spare heat that the engine produces, reducing the thermal energy that the GSHP system has to provide. The overall efficiency is slightly better that the GSHP alone because the thermal energy used to produce electrical energy is not wasted.

CCHP+ASHP: in this case the natural gas-fired plant designed for the settlement is a CHP plant (electric power 150 kW), matched with absorption chillers (100 kW) and an ASHP (air-source heat pump) (1400 kW) with a residual power at -5°C of at least 1000 kW. The initial investment for ASHP is reduced in comparison with a GSHP system even if running costs are more elevated due to the reduced efficiency and ASHP has a more performance variability affected by climatic conditions. The CCHP is active only when the price of electrical energy is at the daily highest level.

GSHP: in this case the plant designed for the settlement is a GSHP (1000 kW). This solution is the same of solution n.1 avoiding the use of CCHP system. In this case the whole energy required is provided by the national electrical grid.

ASHP: in this case the plant designed for the settlement is a ASHP (1400 kW) with a thermal power at -5°C at least of 1000 kW; this condition is caused by the reduction of the COP. Therefore heat pump of nominal power of 1400 kW at 7°C is to be used. The costs due to acoustic mitigation of the plant are included. In this case the whole energy required is provided by the national electrical grid.

CB+AC: in this case the plant designed for the settlement is a condensing boiler (1200 kW at least in two units) and an air chiller. This solution is the reference Base Case of this study and the cheapest investment solution but, as it will be shown later it has higher running costs.

GSHP+PV: in this case plant designed for the settlement is a GSHP (1000 kW) with a integrated photovoltaic plant of total peak power 445 kW_p occupying a surface of 5300 m^2 of buildings roof. Such configuration allows producing the same amount of electrical energy required by GSHP to the grid and therefore an annual electrical energy balance to the grid equal to zero.

EGS: in this case plant designed for the settlement is a EGS plant (thermal power 1,7 MW and electrical power 200 kW, power for cooling is 1,12 MW). The system has high investment cost, however it can produce a large amount of energy and it can be highly profitable.

6. Analysis

Different plants are compared on energy, economical and environmental impact parameters to evaluate the cost-effectiveness and sustainability of the solutions. The aim of the analysis is to achieve synthesis parameters to describe overall energy efficiency in term of environmental and economical point of view:

- Energy production of the systems considering the energy used by the plants, so comparing net energy (NE) expressed in MWh;
- Cost of primary energy produced, including all the costs; the parameter used is named unitary thermal energy cost (UTEC) expressed in €/MWh.
- Reduction of carbon dioxide (CO_2) emission, expressed in tons of CO_2 emissions, for each plant solution compared to the base case.
- Cash flow (CS) of the best plant solutions, expressed in € during a lifespan of 25 years.

6.1 Net energy

Net energy is the algebraic sum of primary energy, produced and used, by the different systems considering all energy produced (electrical and thermal in the case of CCHP systems and simply thermal for the other systems); energy used is related to energy needs of the buildings block and running of the plants. Different plants are designed to produce the same amount of thermal energy for the buildings; CCHP plant produces both thermal and electrical energy and, in this study, it is coupled with two different types of heat pump (GSHP and ASHP). These HP are electrical energy driven so that combination of cogenerating system and heat pump it is supposed to be a very efficient system. Electrical energy produced by CHP systems is partly used by heat pumps and partly sold as energy production. The comparison of net energy of the different system is made based on primary energy translating electrical energy using the variable coefficient for local contest [16]. Figure 12 shows the results of this first analysis in which can be seen that EGS and GSHP+PV system have no energy used but EGS has the highest energy production followed by CCHP systems which nevertheless have a large amount of energy used.

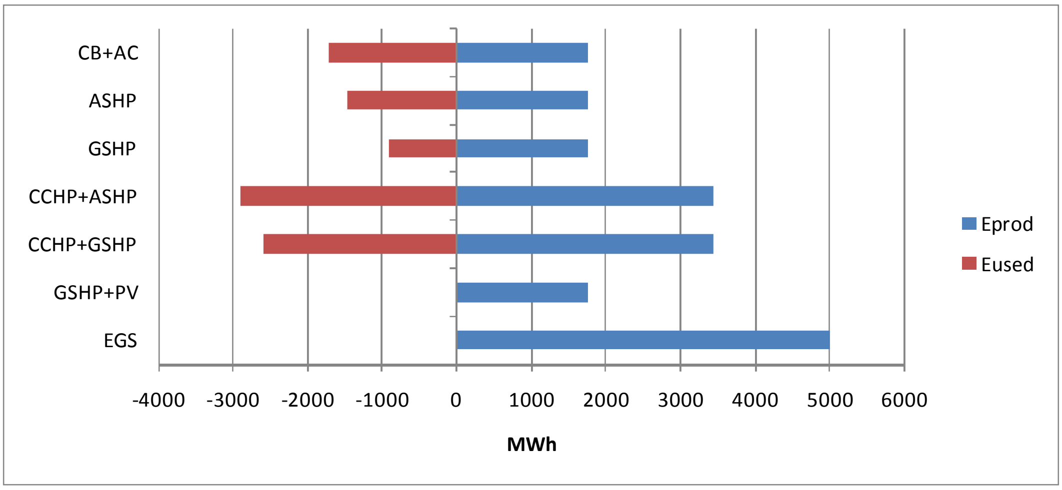


Figure 12 Energy produced and used in the different plant solutions.

Figure 13 shows the results based on Net Energy that is energy produced subtracting energy used. In this case is relevant how GSHP system is more efficient than CCHP systems. Using NE as reference value, CB+AC is the worst solution and will be used as base case, the GSHP+PV has high value of NE producing all energy required to the system by RES and with a zero value of energy consumption, but EGS system has the highest value, 65% more than GSHP+PV and 99% more than the base case.

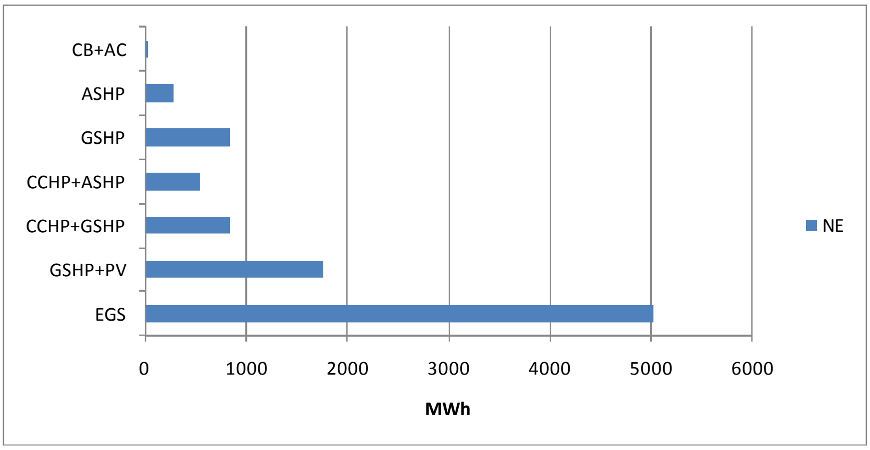


Figure 13 Net Energy for each plant.

6.2 Unitary thermal energy cost

This analysis evaluates economical feasibility and remunerability of the different systems. The economical parameter is calculate evaluating global annual running and payback costs (€) related to annual energy produced (MWh) determining a unitary thermal energy cost (UTEC). The calculation includes the initial investment costs and the running costs (ordinary, extraordinary maintenance, fuel and electrical energy as applicable). The period considered in the analysis is 25 years and takes in account, as described below, all the costs and gains including the feed-in tariffs available in the Italian panorama. The costs are calculated for the different configurations and with an interest rate of 5% in a payback plan of 20 years. The minimal annual profitability of the plants is considered at least 20.000 € for the hypothetical ESCO managing energetically the buildings block. This profitability leads to an annual gain related to initial investment cost between 1-2%. The UTEC value considers some economical feed-in tariffs for the CCHP systems, for photovoltaic plants and EGS. The values calculated considering feed-in tariffs are marked with an asterisk. Cogeneration is assimilated to RES and fuel has a tax exemption that reduces the real cost of natural gas [17]; photovoltaic systems have a feed-in tariff that incentives the kWh produced since 2007. Figure 14 resumes the results of this analysis: CCHP systems cost are reduced by 43% compared to conventional system (CB+AC); simple GSHP system achieves a reduction of 4% and ASHP of 2%. Producing electrical energy all by PV system, thermal energy supplied by GSHP system has cost per MWh that is reduced by 88%. EGS is definitely the most convenient system reducing UTEC by 81% without incentives; considering a feed-in tariff the calculated value is negative in the diagram; this result has no real relevance. In real world this means that it is the only solution in which UTEC can be zero, i.e. no cost will be due for thermal consumption.

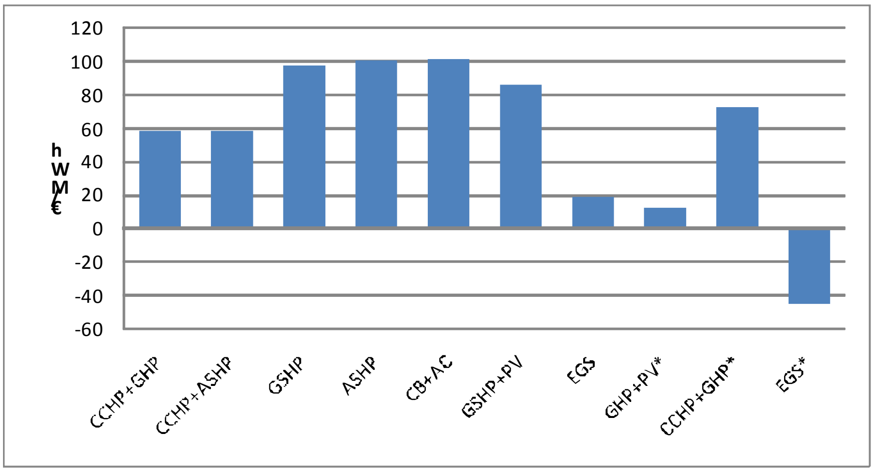


Figure 14 Unitary thermal energy cost (UTEC) for the seven cases with and without considering incentives (The values considering feed-in tariffs are marked with an asterisk).

6.3 Environmental evaluation

Use of GSHP system permits a considerable CO_2 emission reduction avoiding traditional fuels. In Milan area there is the possibility to use underground water or to install vertical boreholes as heat exchanger but in this second case the approval procedure and the bureaucracy required is simpler and the time necessary for the approval may differ up to 18 months. The third phase of the analysis points out the environmental performance of the systems; therefore the study evaluates the CO_2 emissions of the systems adopted. Conventional system with condensing boiler and air chiller (CB+AC) that use thermal and electrical energy to achieve energy targets has the most relevant environmental impact. Use of CCHP systems achieves an important reduction in term of greenhouse emissions, coupling cogeneration with ASHP reduction reaches 24% and with GSHP the advantage is about 41%. These systems without cogeneration have a reduction of 16% (ASHP) and 48% (GSHP). GSHP systems use only electrical energy. In this case electricity comes from the national grid halving the emissions of the conventional system but the more clean system is GSHP+PV solution using electrical energy that has come directly from the sun. Therefore the combination of RES obtains zero carbon emissions for air conditioning; the same result can be achieved by use of ESG system.

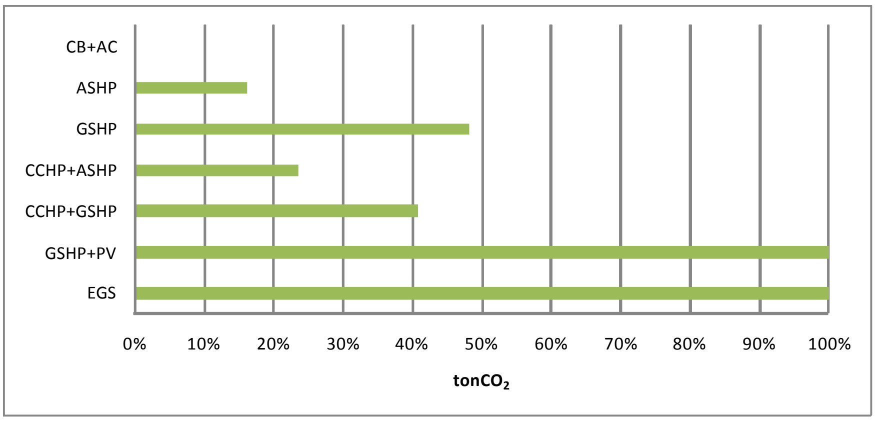


Figure 15 Carbon dioxide emissions reduction for each system compared to the base case.

6.4 Cash flow in 25 years

It is worth also to investigate what would be the economical result if the feed-in tariffs and economical incentives for RES were removed. Considering the lifetime of these systems, the study analyses the cash flow value during 25 years. The annuity rate is calculated as follows:

$$\text{Annuity}_i = \frac{\text{IntRate}}{\left(1 - \frac{1}{(1+\text{IntRate})^{\text{lifetime}}}\right)} V_i \quad (1)$$

Where IntRate (interest rate) is 0.04. The three best plants resulting from the previous analysis are compared calculating cash flow. These plants are CCHP+GSHP, GHSP+PV and ESG.

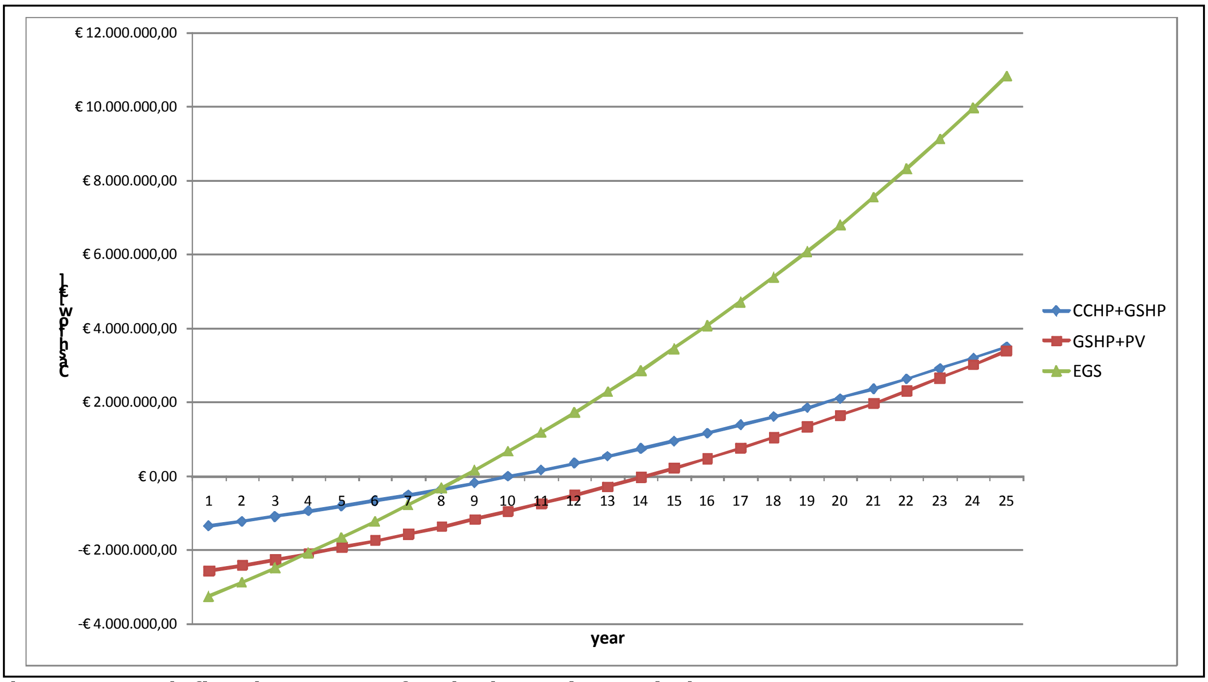


Figure 16 Cash flow in 25 years for the best plant solutions.

Figure 16 shows the same cash flow for CCHP+GSHP and GSHP+PV plants without considering incentives confirming the economical feasibility of coupling RES to GSHP but it is relevant the major economical advantage that is possible to reach with EGS systems.

7. Conclusions

Solutions analyzed without considering incentives have UTEC between 101 €/MWh and 19 €/MWh. Advanced synergic systems as CCHP+GSHP, GSHP+PV show feasibility and payback time less than 15 years without feed-in tariffs and positive cash flow. EGS system, even though the high investment cost, results as the most profitable system. It also reduces primary energy consumption on a national scale in the Italian system in which fossil fuel is mainly used and consequently environmental impact. In the world and also in Europe there are some pilot plants that are showing how to manage the construction and how much energy can be extract with this kind of systems. This study determines that before the 9th year is to be expected the payback of the plant and the cash flow at the 25th year is more than double than the others solutions. On the other hand GSHP+PV have a predictable cost and profitability as return of the investment while EGS systems have a degree of uncertainty quite higher and may lead to profitability lower than estimated and, in areas in which deep underground is unknown due to lack of petroleum/natural gas exploration wells, an higher risk investment. In Italy underground has been analyzed in detail through fossil fuels geological deposit source but the authorization procedure may require more than 2 years to fulfill the step mandatory to get the final authorizations. Increasing numbers of EGS power plants in France, Germany, USA and other areas state clearly that this technology is ready to take a significant role in close future energetic scenario and are profitable even without feed-in tariffs. The main obstacle to widely spread this solution is the high initial investment required not only for the plant itself but also for exploration site and subsequent analysis that usually take between 5 and 10% of the overall investment that can exceed tenths of million euros also in Italy there is a latency time of more than two years to get the whole authorization for the production site with a huge and long financially exposition for the potential investor. The present study shows definitely that even all “the sea of troubles” [18] that has to be overcome leads to high profitability, three times the initial investment during the lifespan of the plant itself.

References

[1] Directive 2010/31/EU of The European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

[2] Legge 9 gennaio 1991, n.10 - *Norme per l’attuazione del piano energetico nazionale in materia di uso razionale dell’energia, di risparmio energetico e di sviluppo delle fonti rinnovabili di energia*.

[3] Decreto Legislativo 19 Agosto 2005, n.192 - *Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell’edilizia*.

[4] Decreto Legislativo 26 Dicembre 2006, n. 311 - *Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia*.

[5] Decreto del Presidente della Repubblica 2 aprile 2009, n. 59 - *Regolamento di attuazione dell'articolo 4, comma 1, lettere a) e b), del decreto legislativo 19 agosto 2005, n. 192, concernente attuazione della direttiva 2002/91/CE sul rendimento energetico in edilizia*.

[6] Decreto di Giunta Regionale 30 dicembre 2009 – n. 8/10965, *Carta Geoenergetica Regionale*, Criteri per la redazione della Carta Geoenergetica regionale in attuazione dell’art. 10, comma 7, della l.r. n. 24/2006.

[7] Ghidorzi S. *Normativa sugli impianti a Bassa Entalpia: l’esperienza di Regione Lombardia, geotermia: Media e bassa entalpia*, EnergEthica: Mostra Convegno dell’energia Sostenibile, Firenze, 23 settembre 2011.

[8] Lim J., *Application of geothermal heat pumps in a renovated campus building*, International Journal of Energy Research, Int. J. Energy Res. 2010; 34:445–453

[9] Chiesa S., *Geotermia e geoscambiatori abbinati a pompe di calore*, European Union Sustainable Energy Week, 11-15 Aprile 2011.

[10] U.S. Department of Energy, *An Evaluation of Enhanced Geothermal Systems Technology Geothermal Technologies Program, Energy Efficiency & Renewable Energy, 2008.*

[11] Fokker, Peter A*., Hydraulic Fracturing in the Hydrocarbon Industry,* 29 Jun - 1 Jul, at Enhanced Geothermal Innovative Network for Europe (ENGINE) Workshop 3, Zurich, Switzerland, 2006.

[12] Takatoshi, I., *Detection of Flow-pathway Structure upon Pore-pressure Distribution Estimated from Hydraulically Induced Micro-seismic Events and Applications to the Soultz HDR Field*. 29 Jun – 1 Jul, at Enhanced Geothermal Innovative Network for Europe (ENGINE) Workshop 3, Zurich, Switzerland, 2006

[13] Massachusetts Institute of Technology, *The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*, Renewable Energy and Power Department, 2006

[14] Delibera di Giunta Regionale VIII/8745 - *Determinazioni in merito alle disposizioni per l’efficienza energetica in edilizia e per la certificazione energetica degli edifici*

[15] Deliberazione AEEG 280/07 - *Prezzi medi mensili per fascia oraria e zona di mercato*, articolo 13.4

[16] Delibera EEN 3/08, *Aggiornamento del fattore di conversione dei kWh in tonnellate equivalenti di petrolio connesso al meccanismo dei titoli di efficienza energetica*, GU n. 100 del 29.4.08 - SO n.107

[17] Decreto Legislativo 20/2007, *Attuazione della direttiva 2004/8/CE sulla promozione della cogenerazione*.

[18] Shakespeare W., "*Hamlet*", 1623

Performances of a unified control for decentralized air handling terminals, blind and lighting in office buildings

G. Masy[1], S. Gendebien[2], N. Hansen[1], L. Prieels[3]

(1) Haute Ecole de la Province de Liège - CECOTEPE , (2) University of Liège, (3) Greencom Development SCRL, Liège, Belgium

Abstract

Office building performances in terms of thermal comfort as well as acoustic and lighting comfort is an important issue that should be achieved with nearly zero energy consumption.

Decentralized air handling terminals (DAHT) are double flow ventilation systems provided with a heat recovery exchanger. They can be integrated in window ledges and controlled through the use of CO_2 probes. A unified control box can be associated to the window including the control of the window blind and of the room lighting.

Compared to centralized double flow systems, DAHT are able to fulfill air quality standards as the fresh air flow is controlled independently from the room heating or cooling loads. Moreover, the supplied fresh air flow can be adapted to the level of occupancy of the whole office Building. DAHT can be coupled to heating fan coils and chilled ceiling to meet thermal comfort criteria.

When controlled in association with blind shading control and window opening sensors, the whole system can be associated to free cooling strategies in order to improve summer comfort.

When controlled in association with lighting control they can provide substantial electricity energy savings.

All those aspects of DAHT performances can be illustrated on a typical office building case study. A model of DAHT can be combined with a model of a whole building envelope, including infiltrations as well as dynamic behavior, allowing comparisons with centralized double flow systems. Results regarding energy consumptions, CO_2 concentration, thermal and lighting comfort can be compared and discussed.

1. Case study

Decentralized air handling terminals (DAHT) are double flow ventilation systems that can be integrated in window ledges. Those systems are relevant to improve the energy efficiency of new office buildings as well as to refurbish existing ones.

A case study was adopted to illustrate the relevancy of that technology. Let's assume a five storey concrete structure office building, North / South oriented, located in Belgium (figure 1). The building site is supposed to be moderately exposed to the wind. The air tightness of the façade is characterized by an air flow value of 10.8 m^3/h per square meter at 50 Pa, equivalent to n_{50}=2 h^{-1}. The internal volume related to the façade area equal 5.1 m^3/m^2.The U-values equal 0.41 W/m^2K for the external walls and 1.4 W/m^2K for the windows. The glazing is characterized by a solar factor of 0.6 and by an optical factor of 0.77. Glazing is provided with external blinds whose transmission factor equals 0.36.

Each office has 18.9 m^2 of floor area and is occupied by two people. The required lighting level is 500 lux. Installed lighting electricity power equals 10 W/m^2 of floor area and electric appliances provides another 10 W/m^2 during occupancy hours. Room heating and cooling is provided by fan coils terminal units. Cooling coils are supposed to balance only the room sensible cooling loads without dehumidifying the indoor air. Ventilation is provided through Decentralized Air Handling Terminals with a 70 m^3/h nominal supply and exhaust air flow. Air flow control is performed through CO_2 sensors whose set point equals 1200 ppm. A minimum 20% nominal air flow is provided even when there is no occupancy. DAHT are provided with heat recovery exchangers whose sensible heat efficiency reaches 0.80 [1] (figure 3). Internal doors to the corridor are provided with grilles.

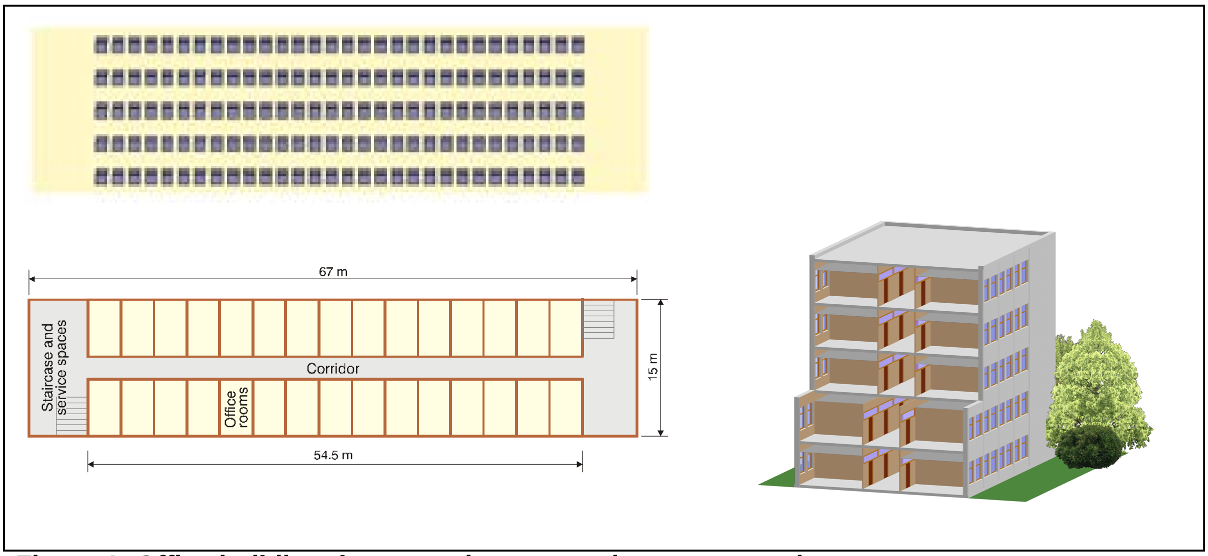


Figure 1: Office building: layout and cross section axonometric.

The building is supposed to be equipped with a fossil fuel boiler whose efficiency equals 0.90 and with an air cooled condenser chiller whose performance coefficient reaches 3 for a condenser air supply temperature of 30°C. The chiller performance coefficient EER is adapted as function of the condenser air supply temperature through the following correlation law:

$$EER_{chiller} = 4.96988448 - 0.0606317101\, t_{a,su,cd} - 0.00017565062.t_{a,su,cd}^{2}$$

Simulations are performed with a 20 minutes time step over a whole year. All consumptions are expressed in final energy consumption per square meter of office floor area.

2. Building model

The building heat balance and thermal mass effect, as well as the building infiltration air exchanges can both be modeled through the use of lumped models, made of resistances capacities and generators, interacting with each other.

2.1 Building heat balance and thermal mass model

The building thermal model gathers external and internal walls, each being modeled either through one resistance if it has a low mass such as for windows, or through two resistances and one capacity if it has a high mass (figure 2). Those equations can be solved through the use of a solver such as EES. The heat flow balance expressed for each temperature node *i* [2], [3]:

$$\frac{dU_i}{d\tau} = \sum_j \frac{t_j - t_i}{R_{ij}} + \dot{Q}_i \qquad t_i = \frac{U_{\tau_0} + \int_{\tau_0}^{\tau_{final}} dU_i}{C_i} \qquad (1)$$

U_i : Energy stored in the thermal capacity *[J]*

C_i : Thermal capacity associated to the temperature node *[J/K]*

t_i, t_j : Temperatures of nodes *i* and *j [°C]*

R_{ij} : Thermal resistance between temperature nodes *i* and *j [K/W]*

$\dot{Q}_i$: Sensible heat flow provided to node *i [W]*

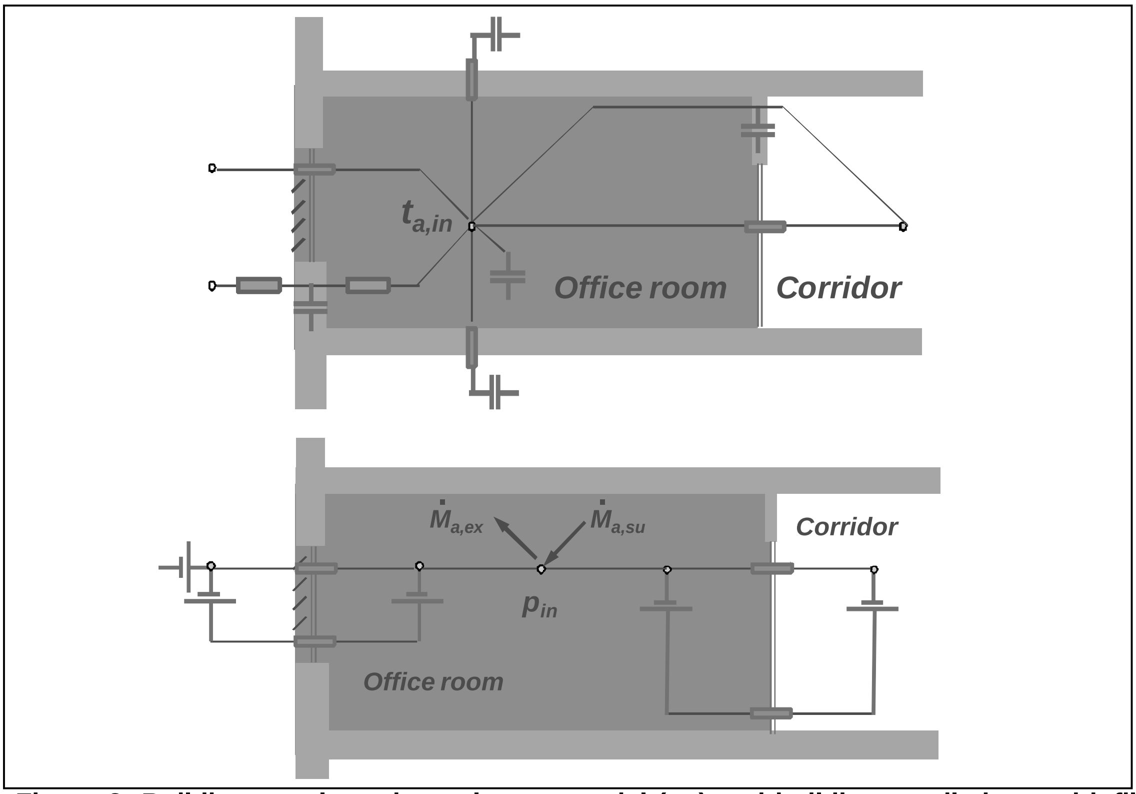


Figure 2: Building envelope thermal mass model (up) and building ventilation and infiltration model (down).

2.2 Building infiltration and ventilation model

The building infiltration and ventilation model can be built through a set of resistances modeling pressure drops through air apertures and pressure generators, due to the wind and buoyancy effects (figure 2). The mass air flow balance is expressed at each node and the pressure balance is expressed along each loop of the network.

A non linear relationship expresses pressure drop as function of mass air flow. It is written in a way that allows mass air flow to be positive or negative, depending on the real air flow direction [4]:

$$\Delta p = K \bullet \left|\dot{M}\right|^n \bullet \dot{M} \quad (2)$$

Δp : Pressure drop through ventilation aperture *[Pa]*

$\dot{M}$: Mass air flow rate through ventilation aperture *[kg/s]*

K: Constant *[Pa.(s/kg)$^{1+n}$]*

n: Exponent ranging from *0* when the flow is laminar and the pressure drop is proportional to the mass air flow rate, to *1* for a turbulent flow where the pressure drop is proportional to the square of the mass air flow rate

The driving forces are due to wind pressure and to buoyancy effects:

$$\Delta p_{buo} = g.\frac{(z_2 - z_1)}{v} \qquad\qquad \Delta p_{wind} = p_c.\frac{u^2}{2.v} \tag{3}$$

Where:

g: Gravity acceleration 9.81 *[m/s²]*

z_2, z_1 Levels over a reference horizontal plane *[m]*

p_C: Pressure coefficient *[-]*

u: Air speed *[m/s]*

v: Air specific volume *[m³/kg]*

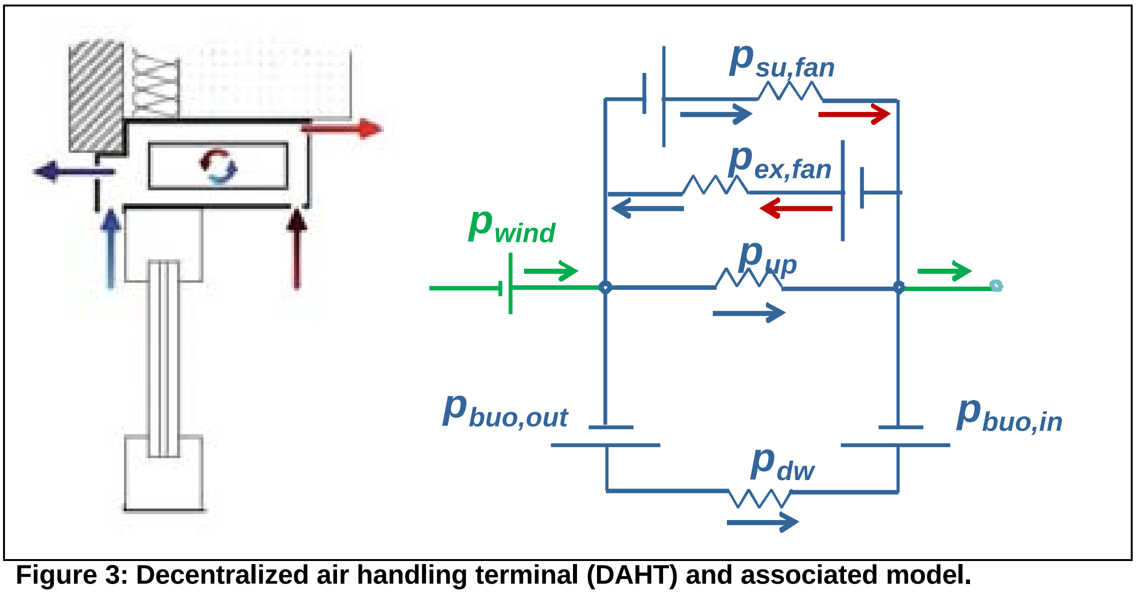


Figure 3: Decentralized air handling terminal (DAHT) and associated model.

A model of a window can be built integrating the stack effect over the window height and a model of the DAHT can be added to the window model [5] (figure 3). DAHT supply/exhaust fans are modelled through a pressure generator followed by a pressure drop resistance, while the heat exchanger adds another pressure drop resistance.

3. Lighting, blind shading and window opening control analysis

Let's assume a unified control box is associated to the window DAHT, including control of the room lighting power and of the window blind opening.

Lighting control is implemented first as it is responsible for a large part of electricity consumptions [4], [7] and as it has a strong impact on the chiller final energy consumption [8]. Figure 4 illustrates the reduction of electricity consumptions due to lighting control: a reduction of 20 kWh/m² per year, is observed for lighting, and a subsequent reduction of 4 kWh/m² for the chiller. The boiler gas final consumption is increased by 1 kWh/m².

The next step is to optimize window blind shading control in order to reduce the solar heat loads without causing an increase of lighting electric power, which would, in turn, induce an increase of chiller energy consumption. The window blind is closed as soon as the solar radiation reaching the window external surface reaches a given threshold, provided the indoor temperature is higher than 22 °C. Figure 5 shows the evolution of the lighting and chiller electricity consumptions for different values of the solar intensity threshold. An optimal value of that threshold is found to be equal to 200 W/m², according to European primary energy conversion factors, respectively equal to 3.31 for electricity and 1.35 for gas, as illustrated on figure 6. A saving of 4 kWh/m² final electricity consumption per year, can be added for the chiller with an optimized window blind shading control, without significantly increase the boiler gas consumption (Figure 4). The electricity consumptions of appliances and fans are respectively equal to 26 kWh/m^2 and 4 kWh/m^2. They are not affected by the lighting and blind control strategies, nor by the free cooling due to window opening.

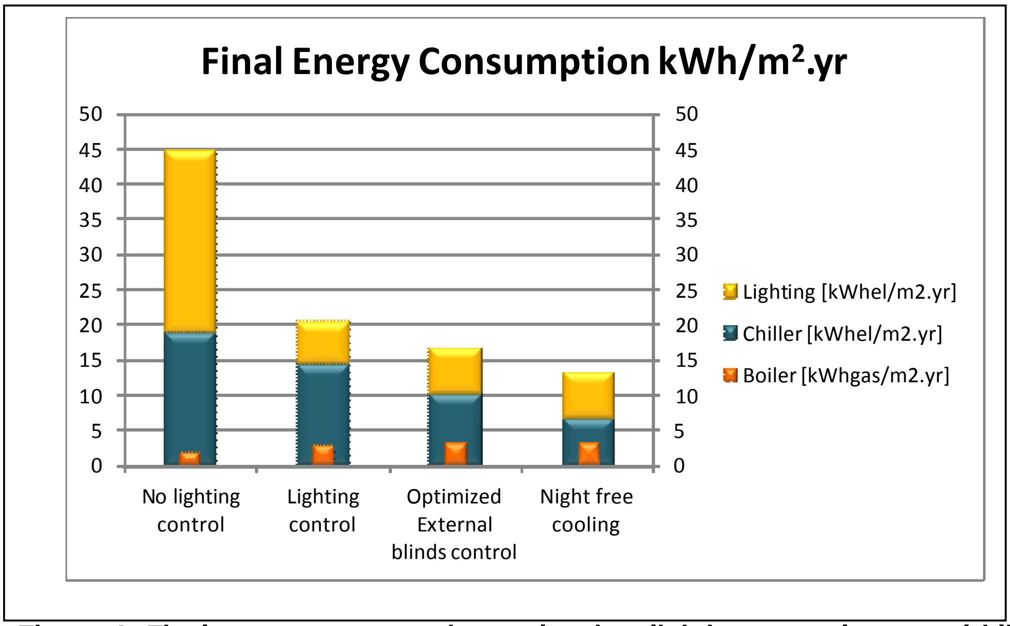


Figure 4: Final energy consumptions related to lighting control, external blinds control and night free cooling.

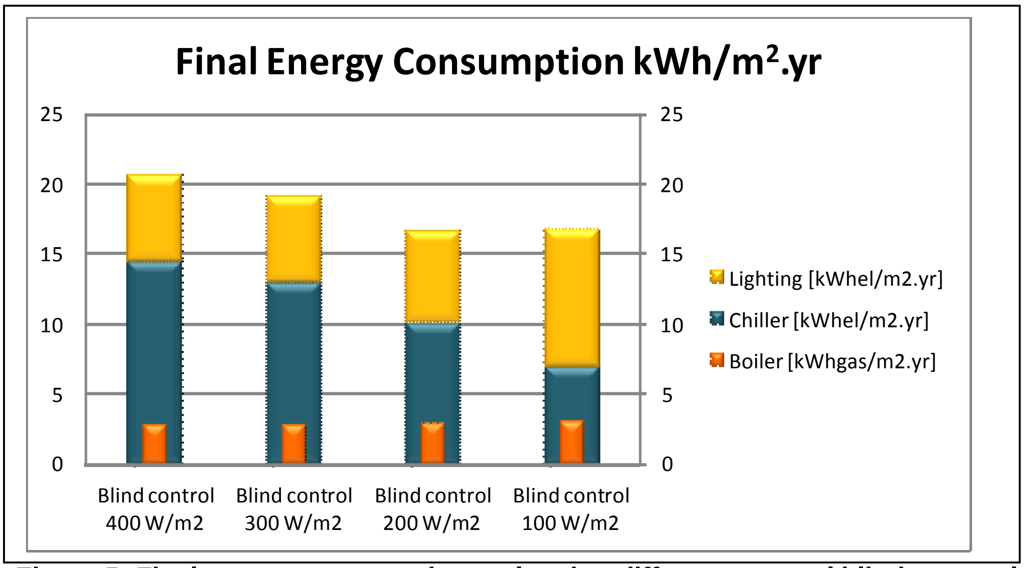


Figure 5: Final energy consumptions related to different external blinds control strategies.

Figure 4 shows that the chiller consumption is still higher than the lighting consumption. It can be reduced by a free cooling strategy performed through window opening during no occupancy hours. A 3.5 kWh/m^2 per year extra energy saving can be added for the chiller when free cooling is performed. This can be done by adding window opening sensors to the DAHT unified control box.

Those strategies of lighting, blind shading on both facades and window opening control are supposed to be implemented for the rest of the study.

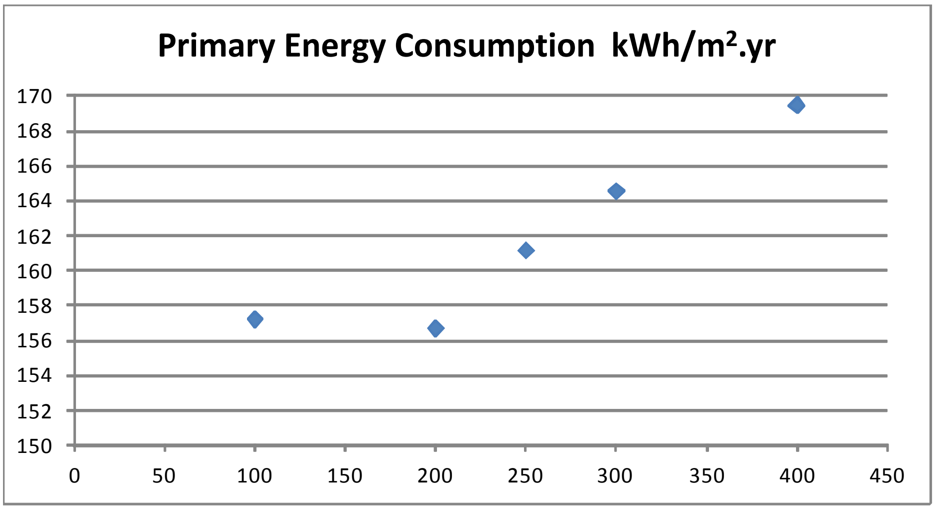


Figure 6: External blinds control optimization.

4. Heat recovery and air flow control

Decentralized air handling terminal are provided with a heat recovery exchanger. Figure 7 illustrates the benefit of such a heat recovery exchanger: the yearly final heating energy consumption can be reduced by 15 kWh/m^2. A subsequent 5 kWh/m^2 increase is observed for the chiller yearly electricity consumption. It is explained by the absence of a bypass that could avoid heat recovery when the room is cooled and the outdoor air is cooler than the indoor air. The absence of bypass is a design option meant to reduce the price of the DAHT. The observed increase of the chiller electricity consumption could be avoided by extending the opportunity to perform free cooling by window opening during office occupancy hours, provided there is no risk of noise or outdoor air pollution.

Decentralized air handling terminal air flow control through CO_2 indoor probe is responsible for 3.5 kWh/m^2 energy saving per year for the chiller consumption.

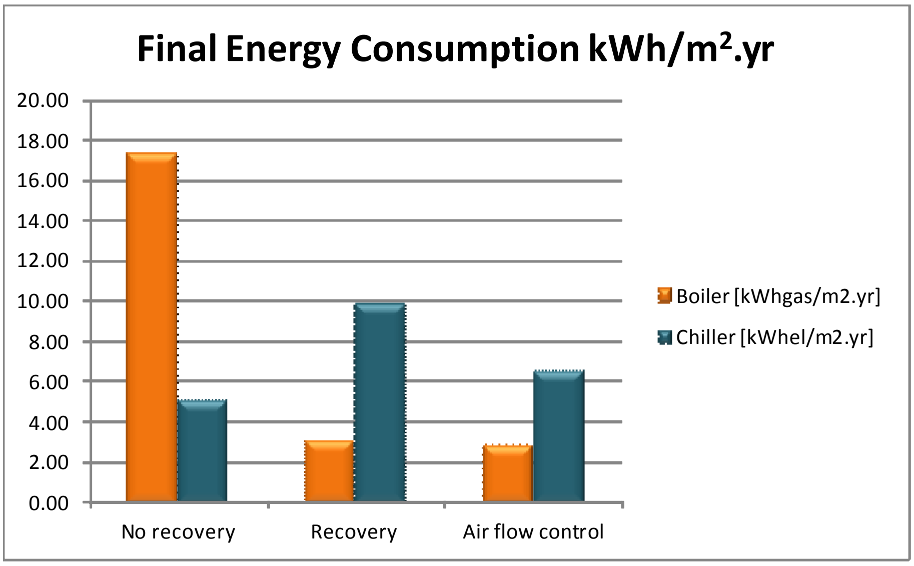


Figure 7: Final boiler and chiller energy consumption related to Decentralized Air Handling Terminals

5. Comparison of DAHT with other ventilations systems

Decentralized air handling terminal performances can be compared with natural ventilation systems, composed of air supply grilles in the façade associated to a ventilation shaft in the corridor, the indoor doors being provided with grilles. Those systems require low boiler heating energy consumptions at first glance (figure 8) but they are not able to reach air quality requirement as can be seen on figure 9, due to the absence of air flow control. Those systems are responsible for rather high chiller cooling energy consumptions as their air flow can't be controlled and as they can't perform heat recovery (figure 8).

Ventilation can also be performed through centralized air handling units, provided with heat recovery exchanger and air flow control. Those systems are able to fulfill air quality requirements as can be seen on figure 9, with a maximum CO_2 concentration of 1200 ppm, but the control of air flow is performed through one probe located either in an office or in the return duct, so that some offices are over-ventilated causing higher boiler heating consumptions than DAHT (figure 8).

Decentralized air handling terminals appear to offer the best performances. When associated with an airtight building envelope, i.e. from n_{50}=2 h^{-1} to n_{50}=0.6 h^{-1}, the yearly boiler heating consumption can still be reduced by 5 kWh/m^2 , with a small increase of the chiller consumption.

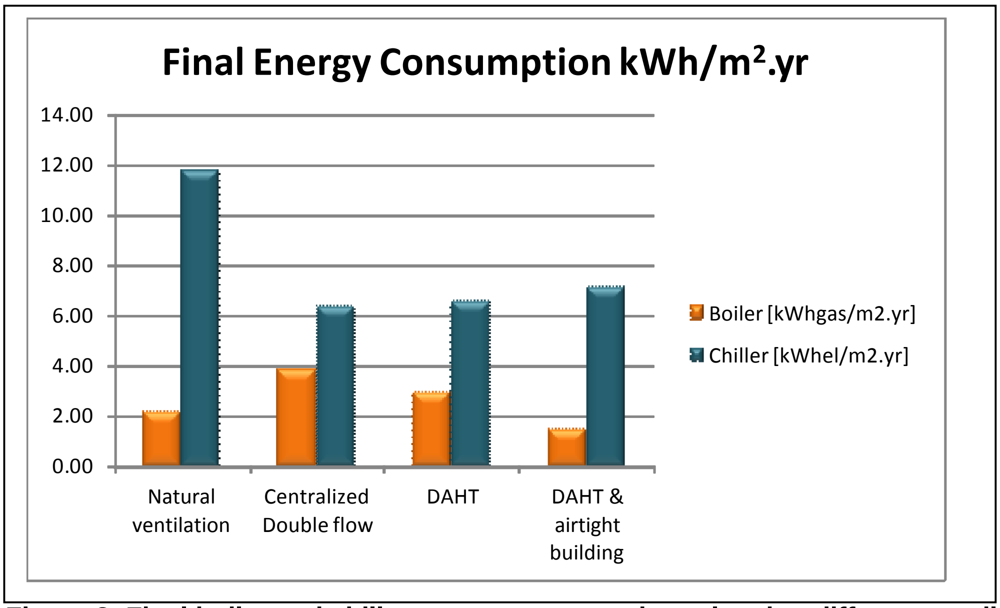


Figure 8: Final boiler and chiller energy consumption related to different ventilation strategies

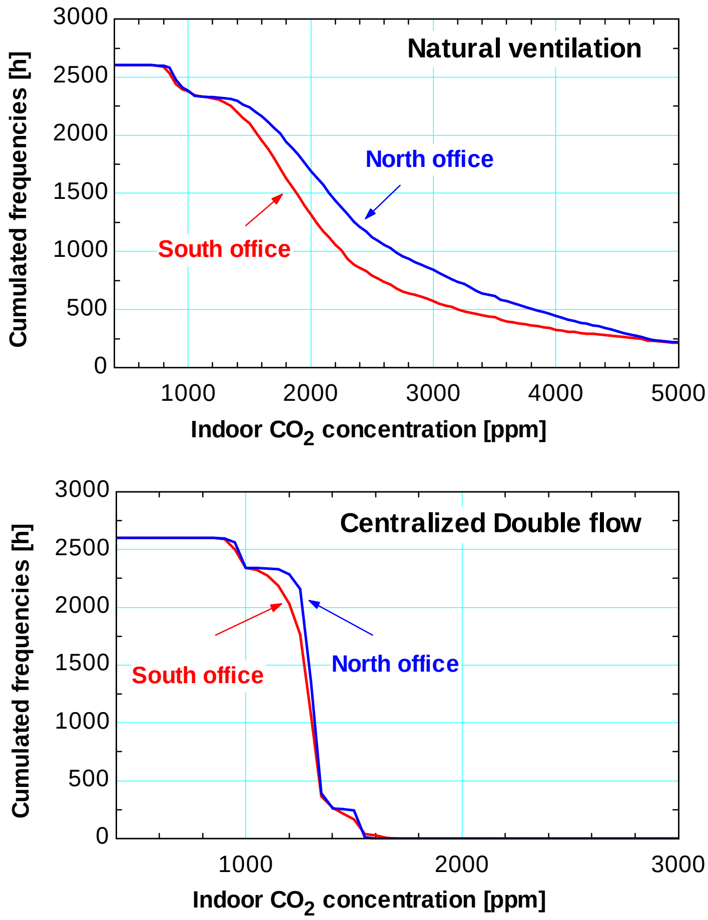


Figure 9: Cumulated frequencies of indoor air CO_2 concentration during occupancy hours over a whole year.

6. Centralized vs. Decentralized ventilation for variable occupancy

The main advantage of decentralized ventilation is that it can be adapted to different occupancy schedules, because air flow control can be performed independently for each office, while the control of air flow in centralized ventilation systems is performed only through one probe located either in an office or in the return duct.

Let's assume the CO_2 probe is located in the South office. The South office remains fully occupied over the whole year (two people), while the North office is either fully occupied too, or occupied by only one people, or not occupied at all. The corresponding yearly boiler and chiller energy consumptions are represented on figure 10. The energy consumption for heating increases for both ventilation systems as internal heat loads due to people are removed from the room, but the increase in energy consumption is higher for the centralized ventilation system (4 kWh/m^2 per year) than for the decentralized one (2.5 kWh/m^2). This is due to the fact that a centralized ventilation system over-ventilates the unoccupied spaces. Even if the centralized system presents a slight higher reduction of chiller consumption, due to the free cooling effect of over ventilation, the total energy consumption is always lower for decentralized ventilation systems.

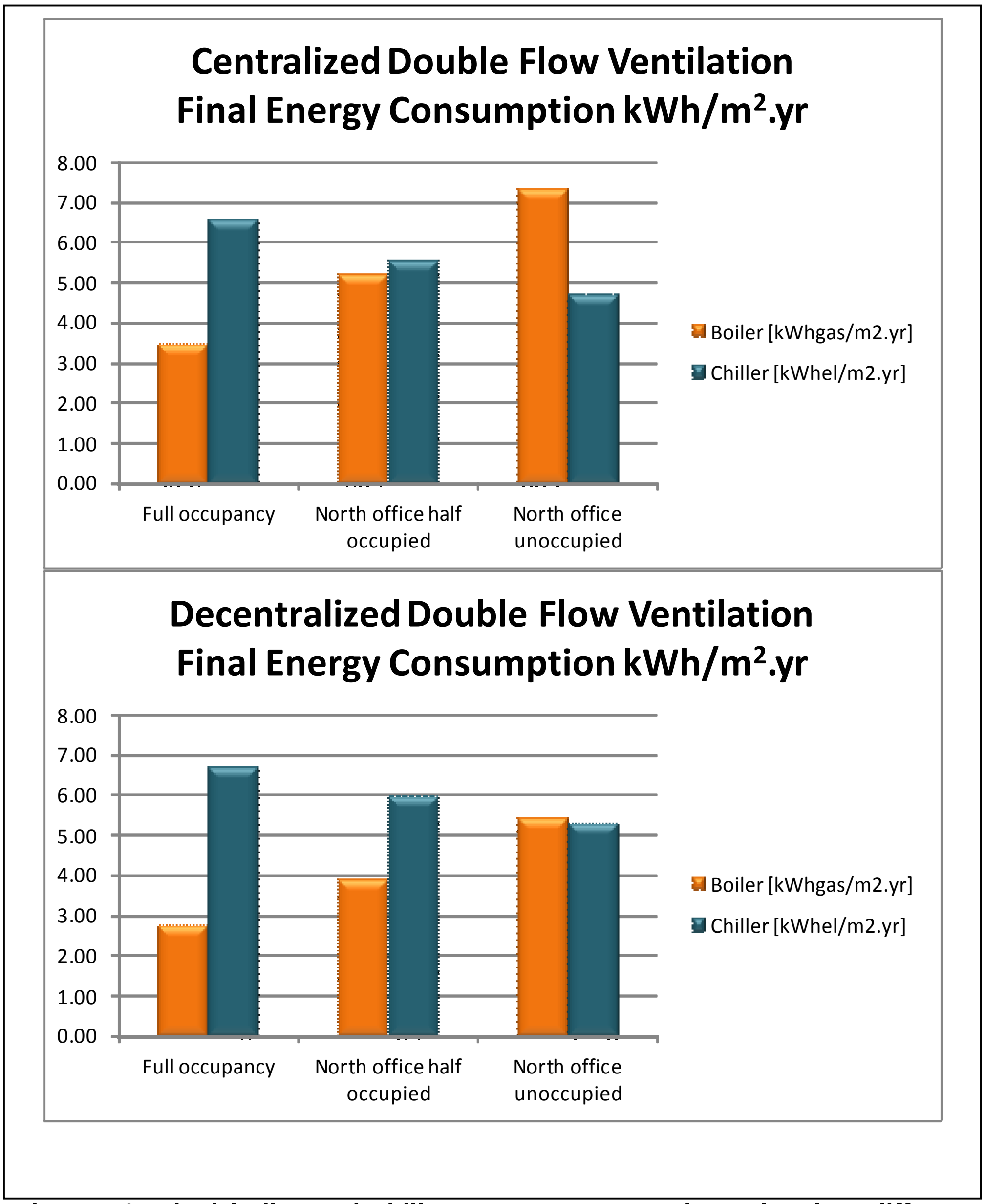


Figure 10: Final boiler and chiller energy consumption related to different occupancies for centralized and decentralized double flow ventilation systems.

7. Conclusion

Decentralized air handling terminals (DAHT), integrated in window ledges, can be associated to a unified control box in order to improve the office buildings energy performances, as well as their thermal and lighting comfort.

Those aspects can be illustrated on a typical office building case study. A model of DAHT can be integrated in a whole building envelope model including thermal mass dynamic behavior coupled with air infiltrations and ventilation, in order to perform various simulations.

When room lighting control is integrated in the unified control box, it provides 20 kWh/m^2 per year electric energy saving, with a subsequent chiller energy saving of 4 kWh/m^2. The boiler gas final consumption is increased by 1 kWh/m^2. An optimal control of window blind shading adds 4 kWh/m^2 chiller electric energy savings. Free cooling through window opening provides an extra saving of 3.5 kWh/m^2 for the chiller.

According to European primary energy conversion factors, respectively equal to 3.31 for electricity and 1.35 for gas, room lighting control yields 78 kWh/m^2 primary energy savings, window blind shading adds up 13 kWh/m^2 and free cooling 11.5 kWh/m^2.

Decentralized air handling terminals are provided with a heat recovery exchanger that reduces the yearly final heating energy consumption by 15 kWh/m^2. They are also provided with a CO_2 indoor probe to control the air flow, so that a reduction of 3.5 kWh/m^2 is obtained for the chiller energy consumption. When associated with an airtight building envelope, i.e. from $n_{50}=2\ h^{-1}$ to $n_{50}=0.6\ h^{-1}$, the yearly heating consumption can still be reduced by 5 kWh/m^2.

Compared to natural ventilation systems whose fresh air flow can't be controlled, DAHT improve indoor air quality in terms of CO_2 concentration, as their air flow can be controlled.

Compared to centralized double flow systems, DAHT are able to fulfill air quality standards as the fresh air flow is controlled independently from the room heating or cooling loads. Moreover, the supplied fresh air flow can be adapted to various occupancy schedules, the control being performed independently for each office, while centralized ventilation systems control the air flow through only one probe located either in an office or in the return duct. This can lead to a difference of 1.5 kWh/m^2 per year heating energy consumption between the two systems, when the building is half occupied.

Acknowledgments

The support of the Walloon Region to the work described in this project, through the funding of the Green+ project in the framework of the "Marshall Plan", is gratefully acknowledged.

References

[1] Masy, G., Lebrun, J., Gendebien, S., Hansen, N., Lengele M., Prieels, L. *Performances of DAHT connected to building air tightness and indoor hygro-thermal climate*. Proc. of the AIVC Tightvent Conference, Brussels, October 2011.

[2] Xu, X. and Wang, S.. *Optimal simplified thermal models of building envelope based on frequency domain regression using genetic algorithm.* Hong Kong Polytechnic University, Kowloon, Hong Kong, China. Proc. of the Energy and Building Conference, 2007

[3] Masy, G. *Definition and validation of a simplified multi-zone dynamic building model connected to heating system and HVAC unit*. PhD thesis, University of Liège, 2008

[4] Masy G., André, Ph. *Total energy use in air conditioned buildings; analysis of main influencing factors.* ASHRAE HVAC&R Research Journal, issue 18 (1), 2011.

[5] Masy, G., Lebrun, J., Prieels, L., Vincent, B. and Hansen, N. *A model of Decentralized Air Handling Terminals interacting with Building Infiltration.* Proc. of the Roomvent Conference, Trondheim, June 2011

[6] Maria Justo Alonso, Bjarne Malvik, Hans Martin Mathisen, *Energy efficiency and indoor climate: modeling of ventilation systems using Contam W.* Proc. of the Roomvent Conference, Trondheim, June 2011

[7] Mc Hugh J., Burns P. J., Hittle D.C. *The Energy Impact of Daylighting.* ASHRAE Journal, vol. 40, no. 5, May 1998

[8] Lawrence T., Roth K., Crawley D.B., Brodrick J. *Emerging Technologies: Toplighting & Lighting Controls For Commercial Buildings.* ASHRAE Journal, vol. 50, no. 9, September 2008

AN EXPERIMENTAL AND NUMERICAL ANALYSIS OF DAYLIGHTING PERFORMANCE FOR AN OFFICE BUILDING

[1]G. Nardini, [1]M. Paroncini, [2]V.R.M. Lo Verso

[1]Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica delle Marche, Italy

[2]Energy Department, Politecnico di Torino, Italy

Abstract

The urgency of increasing energy efficiency in new building design and retrofits has moved lighting simulation into a central role in sustainable lighting design. In fact, good daylighting design can result in energy savings and can shift peak electrical demand during afternoon hours when daylight availability levels and utility rates are high. The shape of the building and its orientation, the reflectances of the building surfaces and the glazed areas are important parameters in the daylighting design of buildings. Glazing systems can cut energy consumption and the associated pollution sources, reduce peak demand, enhance daylighting performance, and improve occupant comfort.

This paper presents the results of a numerical and experimental comparison between the performances of an office building with and without external sunscreens. The aim is to analyse the illuminance distribution and some investigations have also been made with regard to the effect on daylight in rooms when sunscreens are used.

The experimental results were obtained using an office building scale model and a sky simulator. The numerical results were obtained through the ray-tracing program Radiance that accurately predicts the light levels and that produces photo realistic images of the architectural space in all sky conditions: illuminance values are obtained respectively through reference point measurements. The daylighting performances of the office building model with and without the sunscreens have been compared and analysed.

KEYWORDS: Daylighting, office building, sunscreen, artificial sky, Radiance

INTRODUCTION

The importance of daylighting to building design has fluctuated throughout history. It started out as the primary light source and a significant architectural formgiver before the first part of the 20^{th} century, and was then largely ignored in the post-war era as fluorescent light, air conditioning, and cheap energy drove building design. Daylighting attracted renewed interest as a result of the oil crises of the 1970s, and suffered again from declining interest in the 1980s and 1990s as energy concerns lessened. Nowadays, the quest to light buildings with daylight and sunlight is enjoying increasing interest from building owners and architects alike. Three major developments are contributing to this recent surge in interest: latest discoveries of the impact of light on human health, the growing influence of 'green building' and progress on lower-cost, reliable, integrated control technologies to provide the responsiveness needed for comfort and energy savings.

Over the last years a lot of headquarters, office or commercial buildings outlines a particular attention to daylight design. The majority of daylighting experimental studies is for atria-buildings but it's interesting also to consider how the orientation and the fenestration have a daylong solar heat gain factor during sunny days throughout the year. According to S. Daryanani (1984), fenestration must have adequate glare control in order to insure occupant comfort. Otherwise, daylighting savings will not be realized, as the occupants are likely to close blinds or curtains and not benefit from daylighting. In fact, the excessive window glare could even increase energy consumption if supplementary electric lighting is required to counterbalance the unwanted glare at the perimeter or due to the increased energy demand for cooling in response to a high amount of solar gains in summer.

In the search for comfort and maximal energy efficiency in commercial and residential buildings there is a possibility to accurarately select glass type or combination to suit any situation. Various techniques are available to control the amount of solar radiation admitted into a room through windows, including the use of external and internal shading and solar control glasses. When the availability of solar radiation coincides with the demand for light, a use of daylight could give a significant contribution to the global performance of a building, both in terms of energy savings and comfort for occupants. On the other hand, daylight may cause problems with glare on workplaces or other places in the visual environment. Solar shadings are often applied to control glare and to reduce solar gains in order to avoid overheating.

Furthermore, daylight influences the indoor climate that is an important factor for productivity. Good indoor climate increases the productivity of the employees working in the building (Heschong et al., 2003). People are spending more time working on computers and people want to work in the zone closest to the windows to maintain a view out (Christoffersen et al, 1999). Glare problems, such as reflections from monitors, are therefore a relevant issue and the risk of glare increases with larger glazing area and it is essential to provide good quality lighting through the sunscreens.

During the design stage it should be possible to assess the comfort and energy for heating/cooling, if the building is wanted to function properly. The situation at present is that sunscreens are seldom designed during the design stage, but they are installed as an emergency measure when problems are encountered, i.e. after the first summer that the building has been in use. It is difficult to market shading devices and to justify their use unless they can be accompanied by a sound assessment of the effects on cooling load and indoor temperature. The difficulty is that there is a lack of relevant and comparable data regarding the amount of solar radiation that is transmitted through different types of sunshades and their performance in combination with windows. As a result, potential of effective solar protection is not considered during design. In turn, this results in designing and installing unnecessarily large air conditioning systems, with high investment and running costs.

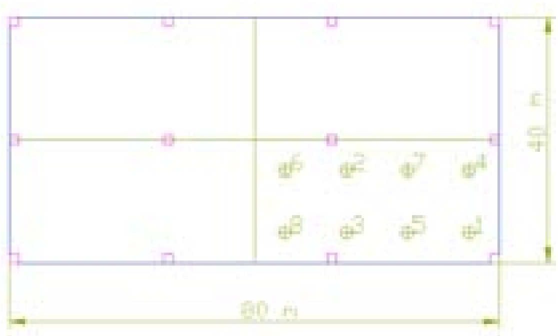
A scale model could be considered a tool of great interest since the behaviour of daylight penetrating into and inter-reflecting within a scale model is considered similar to how it would be in a full scale building. The scale model was made in order to enable the reproduction of every interior or exterior details that influence the daylight penetration into the building and its distribution. For these reasons in this work a scale model with and without the sunscreens and a sky simulator were used to predict the daylight penetration and distribution into an office building. A 1:100 scale model of a five storey office building was achieved. The scale model of the office building with and without sunscreens has been tested in a sky simulator in Torino, Italy (at the Politecnico di Torino) to obtain objective and reproducible sky conditions to analyse and compare different design options. A numerical investigation is carried out through Desktop Radiance software. The experimental and numerical results are compared to verify the validity of the numerical data. These data could be utilized in the research for comfort of occupant and energy saving in daylight strategies.

THE SCALE MODEL AND THE EXPERIMENTAL INVESTIGATION

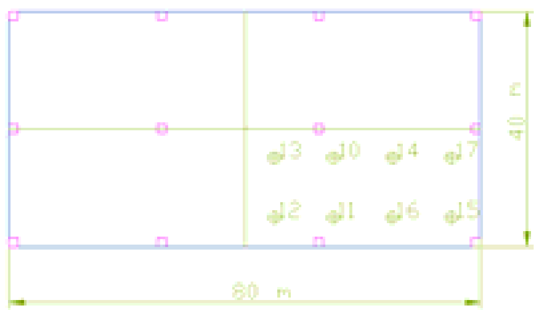
The physical models for lighting are independent of the scale so a scale model is used to evaluate the behaviour of light in an office building. A scale model is valuable for a pre-validation of the real performances of daylighting strategies in a new building. In fact, a model allows quick changes in geometry and surface characteristics providing qualitative data from photographs, for example, and quantitative data of the illumination in the space to check the agreement between visual needs and daylighting. The use of a scale model and of a sky simulator makes it possible to obtain a representation of the dynamic lighting within a space and shows the quantitative and qualitative performance of the daylighting system. The scale model utilized in this study reproduces exactly the geometry of the space and the surface properties of the materials. The model simulates an office building of 80 × 40 m. The model reproduces in a 1:100 scale a five storey office building. The structure of the model is in ply-wood and it is fixed on a stiff base, the wall and floor surfaces are simulated using card of different colours that specifically reproduce reflectance values: 53% for the floor, 73% for the ceiling. The reflectance values of the material used in the model were measured under conditions of diffused light using a spectrophotometer. The external surface of the building is glazed (curtain wall), the glass utilized is clear and its transmittance (optical factor) value is 86%.

Glazing systems can cut energy consumption and the associated pollution sources, reduce peak demand, enhance daylighting performance, and improve occupant comfort. Unfortunately, with the increase of the temperature, comfort for occupants decreases in the space due to the higher mean radiant temperature of the surfaces. Buildings with sunscreens can cut the investment cost for cooling and ventilation installations, reduce energy use and create the conditions for good thermal and visual comfort. So the external sunscreens are installed in three floors of the south-facing façade of the building.

The scale model of the office building with and without sunscreens has been tested in a sky simulator in Torino (at the Politecnico di Torino) to obtain objective and reproducible sky conditions to analyse and compare different design options (Agemo at al. 2007). The facility is a sky scanning simulator: it is a 7 m diameter structure with 25 luminaires, corresponding to one-sixth of the whole sky dome. Actual illuminance values inside models are obtained by adding the partial values measured for a sixstep scan of the scale model situated in the centre of the hemisphere. The luminance distribution of the whole sky is obtained by opportunely varying the luminance of each luminaire for each rotation. This way, different sky conditions can be reproduced (overcast, clear and intermediate conditions) according to both standard models and real luminance values recorded at IDMP (International Daylighting Measurement Programme) measuring stations. The luminaires are actually positioned according to subdivision model of the sky proposed by Tregenza for sky luminance measurements and which is assumed by the CIE in the IDMP.The reproducibility of a sky luminance distribution using the sky simulator allows to make a comparison of several daylighting strategies for the same boundary conditions. The model was located under a luminous vault and it was fixed to a rotating model support that simulated, with successive rotations, the whole ceiling vault. The measurements were carried out with photometers positioned at the height of the working plane (0.85 m). The photometers are fixed in the first and fifth floor to evaluate the daylight levels under an overcast sky.



Points of measurements for the first floor



Points of measurements of the fifth floor

Figure 1 Points of measurements

Scale model with photometers

Scale model during the simulation in the sky simulator

Figure 2 Scale model without the sunscreens

	
Scale model with photometers	Scale model during the simulation in the artificial sky

Figure 3 Scale model with the sunscreens

All the data were evaluated in terms of Daylight Factor. The horizontal daylight factor was taken in several positions on the first and fifth floor to evaluate the daylight levels under an overcast sky. Recently, the international research has moved towards a dynamic approach to daylighting based on annual simulations and assessments, so as to account for the variation of both skylight and sunlight for the specific location under analysis (the approach is known as 'climate-based daylight modeling CBDM' (Mardaljevic 2008). In response to this, a new series of metrics has been proposed in literature (Reinhart et al. 2006), the so-called 'dynamic daylight performance metrics DDPM', which are parameters able to account for the dynamic variation of daylight and sunlight conditions during the course of the year. Neverthekess, it should be stressed out how the daylight factor criterion still remains the only one prescribed in national and international standards and code to assess the daylighting design. For this reason, it was used as indicator in this study.

THE NUMERICAL INVESTIGATION

The behaviour of the model was simulated with Radiance. The first step in the process of performing a daylight analysis is the creation of a 3D model that can be detailed appropriately using the Desktop Radiance library of materials and glazings. The diffused indirect calculation to obtain the daylight factor is very interesting for this study in order to make a daylight analysis of the office building. The evaluation of the daylight factor derives from the irradiance predicted by a backward raytracing technique that reproduces realistic 3-D displays of the daylight conditions inside the building. The irradiance value from the standard output of rtrace is converted directly to illuminance (Ward, 1994). The numerical data obtained under a CIE Overcast Sky, were compared with the experimental measurements with the aim of verifying their agreement.

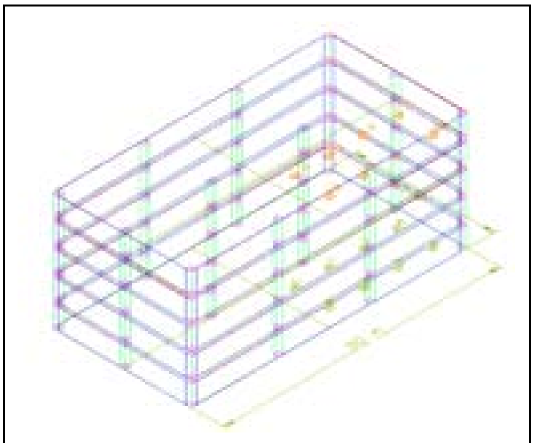


Figure 4 Cad model

DAYLIGHT FACTOR ANALYSIS

The DF is representative of the lighting conditions due to specific sky luminance distribution. While the CIE clear sky distribution is a function of the solar altitude and azimuth and needs a set of factors relating to all solar positions to be represented, a CIE overcast sky is a function of the the visible sky element altitude only and it can be described by a single factor independent of time. This means that if we need a reproducible, fast and easy to handle tool to estimate daylight factor in rooms adjacent to windows in an early design stage it is useful to resort to an overcast standard sky independent of location and time; the evaluation under a clear sky with or without sun can be postponed to a more deepened investigation on the design parameters. The Desktop Radiance software has been used to determine the daylight factor, under a CIE overcast sky. The choice of the first floor is useful in evaluating the worst daylight conditions. Tables 1 and 2 and Figures 5 and 6 show the comparison between the experimental and numerical data: the data show a maximum percentage deviation (• %) of 12,31% on the first floor with a maximum value of 9,72% on the fifth plane of the model without the sunscreen. The high percentage deviation in these points could depend on a shifting between the position of the sensor in the scale model and the point of measurement in the computer model or by the investigation of only a quarter of the model.

Table 1 Experimental and Numerical Daylight Factor on a working plane at the first floor of the building

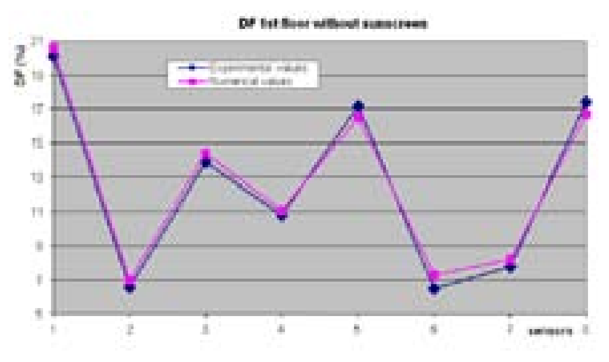
Experimental and numerical DF without the sunscreens				Experimental and numerical DF with the sunscreens			
sensor	DF exp.	DF num.	• %	sensor	DF exp.	DF num.	• %
1	20,1	20,6	2,49	1	19,7	20,2	2,54
2	6,6	7,0	6,06	2	6,5	6,9	6,15
3	13,9	14,4	3,60	3	13,8	14,2	2,90
4	10,8	11,1	2,78	4	10,9	11,2	2,75
5	17,2	16,5	-4,07	5	16,8	16,1	-4,17
6	6,5	7,3	12,31	6	6,3	7,0	11,11
7	7,8	8,2	5,13	7	7,7	8,1	5,19
8	17,4	16,7	-4,02	8	16,8	16,1	-4,17

Table 2 Experimental and Numerical Daylight Factor on a working plane at the fifth floor of the building

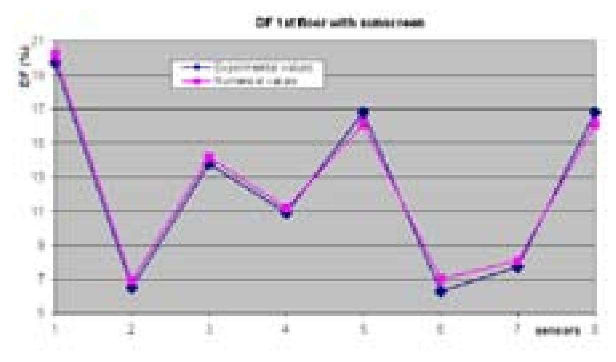
NOTA: concordo con il revisore: anzichè il numero del sensore avrebbe più senso mettere almeno la distanza dalla finestra

Experimental and numerical DF without the sunscreens				Experimental and numerical DF with the sunscreens			
sensor	DF exp.	DF num.	• %	sensor	DF exp.	DF num.	• %

	10	7,9	8,5	7,59			1	5,7	6,2	8,77
	11	15,3	14,7	-3,92			2	8,4	8,6	2,38
	12	17,9	18,7	4,47			3	8,9	9,3	4,49
	13	7,2	6,5	-9,72			4	5,0	4,7	-6,00
	14	10,5	11,0	4,76			5	8,3	8,1	-2,41
	15	25,2	25,6	1,59			6	18,7	18,4	-1,60
	16	18,8	19,8	5,32			7	10,9	11,6	6,42
	17	19,0	17,4	-8,42			8	16,6	17,1	3,01

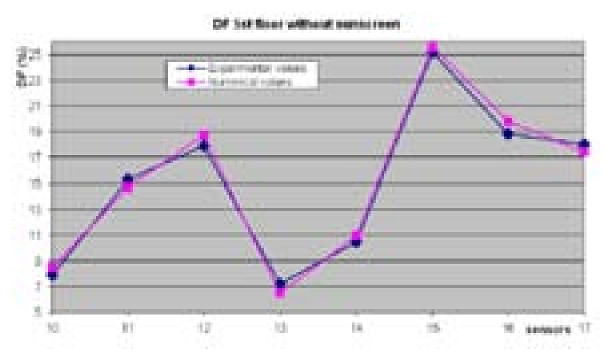


DF on a working plane at the first floor of a building without the sunscreens

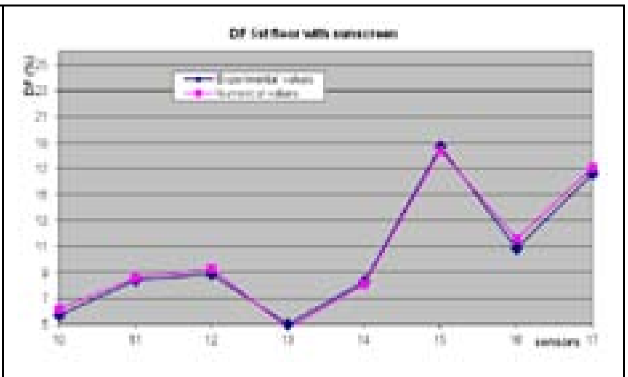


DF on a working plane at the first floor of a building with the sunscreens

Figure 5 Comparison between the experimental and numerical investigation



DF on a working plane at the fifth floor of a building without the sunscreens



DF on a working plane at the fifth floor of a building with the sunscreens

Figure 6 Comparison between the experimental and numerical investigation

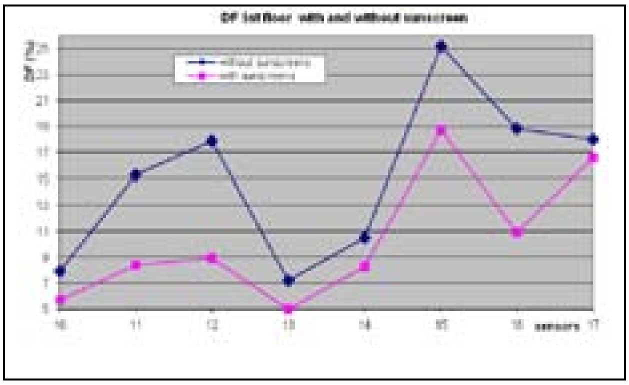


Figure 7 Comparison between the experimental Daylight Factor on a working plane at the fifth floor of a building with and without the sunscreens

CONCLUSION

In this work, the numerical and experimental results about a daylighting analysis realised for an office building are shown. The study has the goal to assess the illumination performances of the building in terms of daylight factor distribution with and without the external sunscreens to control the exposition to the solar radiation of the south façade.

The experimental results were obtained with the use of a 1:100 scale model. The model was tested under a sky simulator at the Politecnico di Torino. The numerical data, obtained under a CIE Overcast Sky, are compared with the experimental measurements and a good agreement is verified.

This investigation cannot be considered finished, as several aspects need further research. In fact, the analysis does not consider the effect of a clear sky and of the direct sun but, as in Mediterranean climates these are the norm, the analysis of the internal daylight distribution under a CIE clear sky with and without sun will be the logical extension of this work. Moreover, it would be interesting to extend the analysis to the other floors of the buildings, studying the distribution of the DF on the several storeys also with a different distribution of the working spaces. Certainly an integrated parametric analysis of lighting and thermal characteristics in office buildings could be desirable in the future development of research.

ACKNOWLEDGEMENTS

This investigation was carried out with financial support from Research Project of National Interest (PRIN 2008).

REFERENCES

[1] Sytal Daryanani,1984, *Design Consideration for Daylighting of New Commercial Buildings*, Energy and Buildings, 6,109-118 , Elsevier Sequoia NL

[2] Ward, G., 1994. *The Radiance lighting simulation and rendering system*. Computer Graphics Proc. Annual Conf. Series, pp. 459–172

[3] Christoffersen J. et. al (1999). *Vinduer og dagslys .– en feltundersøgelse i kontorbygninger SBI-rapport 318*, Danish Building Research Institute, Denmark. (In Danish)

[4] Heschong L. et. al. (2003). *Windows and offices: A study of Office Worker Performance and the Indoor Environment*, California Energy Comission, USA.

[5] Aghemo et al., 2007, *The approach to daylighting by scale models and sun and sky simulators: a case study for different shading systems*, Building and Environment, BAE1907, Vol 43/5 pp 917-927, DOI information: 10.1016/j.buildenv.2007.01.020

[6] Mardaljevic J., 2008, *CIE Division 3 Reportership R3-26, Climate-based daylight analysis*

[7] Reinhart C. Et al. 2006, *Dynamic daylight performance metrics for sustainable building design*. Leukos, vol. 3 (1), pp.1-25, 2006

[8] Paroncini et.al. (2004). *Daylight factor prediction in atria building designs*. Solar Energy 76,669-682

[9] Nardini et.al (2006). *The comparison between numerical and experimental values of an atrium building*, SET 2006

[10] Papamichael (2000). *Desktop Radiance. A New Tool For Computer Aided Daylighting Design*, ACADIA Quarterly vol.19, no.2, pp.9-11.

[11] Guest Editorial, 2006, *Daylighting-Light, form and people, Energy and Buildings*, 38, 715-717.

[12] Bodert et.al. (2006), *A guide for the building of daylight scale models*, PLEA 2006

[13] Li et.al. (2008), *An analysis of daylighting performance for office building in Hong Kong, Building and Environment*, 43, 1446-1458.

[14] Reinhant et.al. (2001), *Validation of dynamic Radiance-based daylight simulations for a test office with external blinds*, Energy and Building, 33, 683-697.

[15] Cheng et.al. (2007), *A mini-scale modeling approach to natural design daylight utilization in building design*, Building and Environment, 42, 372-384.

Indoor lighting in an existing office building - energy efficient refurbishment

MSc Tor Mjøs, Norconsult AS

Affiliation: PhD Pål Johannes Larsen, Norconsult AS

Abstract

The paper will present both the results and the practical challenges that occur when retrofitting lighting installations in existing buildings, in this case the 20 year-old head-office building of Norconsult in Oslo, Norway. The retrofit consisted of single measures as well as general measures to reduce the total energy consumption of the building, including heating, cooling and ventilation. The retrofit project had a special focus on measures to improve the energy efficiency of the lighting installations.

Overall, a reduction of 40 % in total energy consumption was achieved from implementing all the energy saving measures. Due to the cold climate, the heat generated from the lighting installation influences the overall results and the energy balance of the building.

The basis for the calculation of energy consumption for indoor lighting is given in the European standard EN-15193. The standard also allows for the use of measured values, and gives guidelines on how to employ control systems. The paper also looks into these issues regarding existing buildings.

Finally the article summarizes the experience gained during the implementation of a full scale project; these may provide some basic guidelines to the reader for their own retrofit projects.

Figure 1 Test case building, Norconsult head office, Oslo, Norway

Introduction

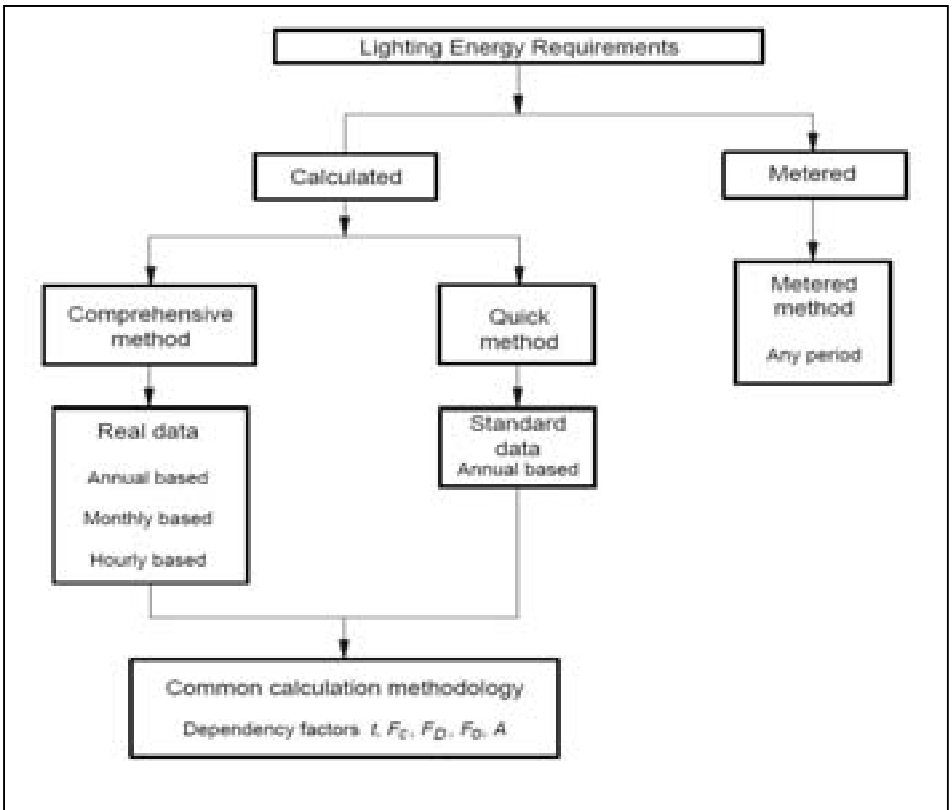
The study is based on the full scale project at the Norconsult head office in Sandvika, Norway. The project started in 2007 when the energy efficiency audit was made; the basic energy consumption was calculated and monitored. The majority of the undertaken measures were outlined in the audit report. Saving potential was set to 34 %, approximately 1,4 GWh. The implementation took place from summer 2009 until autumn 2011.

1 Calculation of energy consumption for lighting according to EN-15193

The European standard is titled “Energy Performance for Buildings – Requirements for Lighting” [1]. It describes in detail the procedure for calculating the annual energy consumption used for lighting. By introducing the LENI - Lighting Energy Numeric Indicator - it also provides a simple method to illustrate energy performance of the installation.

The normative part of the standard goes into detail on how to calculate the consumption, while the annexes, which are only informative, give examples on several measures to improve the performance

The standard gives three (Figure 2) options; quick or comprehensive calculation methods, or energy metering method. For most practical applications, the comprehensive calculation method (usually on an hourly or monthly basis) is recommended.



To set up the calculation, the specific parameters of the building must be found; floor and window areas, geographical orientation of the facades, operating hours etc. Then the specific lighting parameters must be found;

- Installed power consumption
- Parasitic power consumption

Based on the above data, the annual theoretical consumption can be found.

LENI (the performance indicator) is highly dependent on several additional factors influencing the energy consumption, given a dynamic installation;

- tD, tN Operating hours (day and night)
- FC Constant illuminance regulation
- FD Daylight utilization
- FO Occupancy situation (Figure 3)

The LENI is expressed in annually consumption, kWh/m2. In the annex, i.e. the table for occupancy factors for several standardised switching methods can be found:

Table D.1 — F_{OC} values

Systems without automatic presence or absence detection	F_{OC}
Manual On/Off Switch	1.00
Manual On/Off Switch + additional automatic sweeping extinction signal	0.95
Systems with automatic presence and/or absence detection	F_{OC}
Auto On / Dimmed	0.95
Auto On / Auto Off	0.90
Manual On / Dimmed	0.90
Manual On / Auto Off	0.80

Figure 3 Recommended values for switching modes

But any metered valued, if validated, can be applied for the given area. The complete Table F.1 (Figure 4) summarizes standard values for the individual factors.

Annex F
(informative)
Benchmark values and lighting design criteria
Table F.1 — Bench mark default value

	Qual. class	Parasitic Emergency kWh/(m²year)	Parasitic Control kWh/(m²year)	PN W/m²	t_D h	t_N h	F_c no cte illuminance	F_c cte illuminance	F_o Manu	F_o Auto	F_D Manu	F_D Auto	no cte LENI Limiting value Manu kWh/(m²year)	no cte LENI Limiting value Auto kWh/(m²year)	cte illuminance LENI Limiting value Manu kWh/(m²year)	cte illuminance LENI Limiting value Auto kWh/(m²year)
Office	*	1	5	15	2250	250	1	0.9	1	0.9	1	0.9	42.1	35.3	38.3	32.2
	**	1	5	20	2250	250	1	0.9	1	0.9	1	0.9	54.6	45.5	49.6	41.4
	***	1	5	25	2250	250	1	0.9	1	0.9	1	0.9	67.1	55.8	60.8	50.6
Education	*	1	5	15	1800	200	1	0.9	1	0.9	1	0.8	34.9	27.0	31.9	24.8
	**	1	5	20	1800	200	1	0.9	1	0.9	1	0.8	44.9	34.4	40.9	31.4
	***	1	5	25	1800	200	1	0.9	1	0.9	1	0.8	54.9	41.8	49.9	38.1
Hospital	*	1	5	15	3000	2000	1	0.9	0.9	0.8	1	0.8	70.6	55.9	63.9	50.7
	**	1	5	25	3000	2000	1	0.9	0.9	0.8	1	0.8	115.6	91.1	104.4	82.3
	***	1	5	35	3000	2000	1	0.9	0.9	0.8	1	0.8	160.6	126.3	144.9	114.0
Hotel	*	1	5	10	3000	2000	1	0.9	0.7	0.7	1	1	38.1	38.1	34.6	34.6
	**		5	20	3000	2000	1	0.9	0.7	0.7	1	1	72.1	72.1	65.1	65.1
	***	1	5	30	3000	2000	1	0.9	0.7	0.7	1	1	108.1	108.1	97.6	97.6
Restaurant	*	1	5	10	1250	1250	1	0.9	1	1	1	-	29.6	-	27.1	-
	**	1	5	25	1250	1250		0.9	1	1	1	-	67.1	-	60.8	-
	***	1	5	35	1250	1250	1	0.9	1	1	1	-	92.1	-	83.3	-
Sport places	*	1	5	10	2000	2000	1	0.9	1	1	1	0.9	43.7	41.7	39.7	37.9
	**	1	5	20	2000	2000	1	0.9	1	1	1	0.9	83.7	79.7	75.7	72.1
	***	1	5	30	2000	2000	1	0.9	1	1	1	0.9	123.7	117.7	111.7	106.3
Retail	*	1	5	15	3000	2000	1	0.9	1	1	1	-	78.1	-	70.6	-
	**	1	5	25	3000	2000	1	0.9	1	1	1	-	128.1	-	115.6	-
	***	1	5	35	3000	2000	1	0.9	1	1	1	-	178.1	-	160.6	-
Manufacture	*	1	5	10	2500	1500	1	0.9	1	1	1	0.9	43.7	41.2	39.7	37.5
	**	1	5	20	2500	1500	1	0.9	1	1	1	0.9	83.7	78.7	75.7	71.2
	***	1	5	30	2500	1500	1	0.9	1	1	1	0.9	123.7	116.2	111.7	1.5.0

Figure 4 Lighting design criteria - Benchmark default values

2 Saving potentials, case study

The basis for the findings in this paper is based on a real case study of a 17.000 m2 office building. Based on historical monitoring of consumption as well as more detailed metering just before and after implementation, the outcome has been identified and verified. The findings are divided into the following main topics:

- Installation of new luminaries (T5) in the offices; occupancy detection
- Installation of new luminaries (T5) in the garage, bicycle parking; occupancy detection
- Installation of new luminaries (LED) in corridors; daylight compensation
- Installation of new luminaries (LED) in meeting rooms; occupancy detection
- Installation of new luminaries (LED) in toilets, storage rooms etc; occupancy detection

In addition to the lighting measures, several HVAC measures were also implemented.

2.1 Highest savings rate obtained in the car parking

The garage is located in the basement of the building, over two floors. The original installation was on continuously for 100% of the time, even during weekends. By full retrofit of 2x58W into 1x49W and introduction of occupancy detection, the reduction was considerable. The calculated LENI values for the old and new installations were respectively 16 and 3 (kWh/m2 -year).

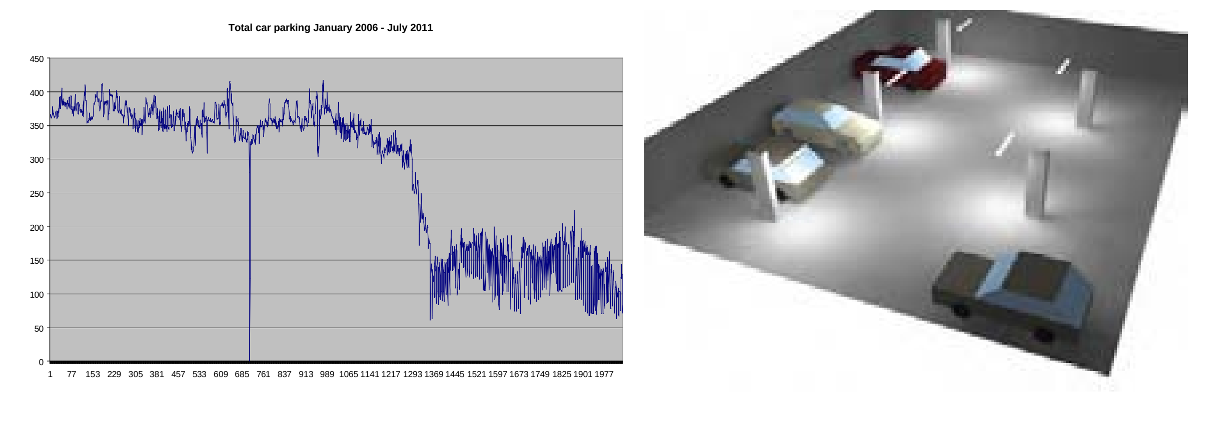


Figure 5 Change in consumption before, during, and after implementation in the car parking garage in the basement with no daylight.

Looking at the changes only related to lighting, the energy consumption was reduced by 75% (Figure 5). Several operational strategies have been tested out, resulting in fixed dimmed level at 10% (as a minimum even during night). The four zones are individually dimmed after 10 minutes inactivity.

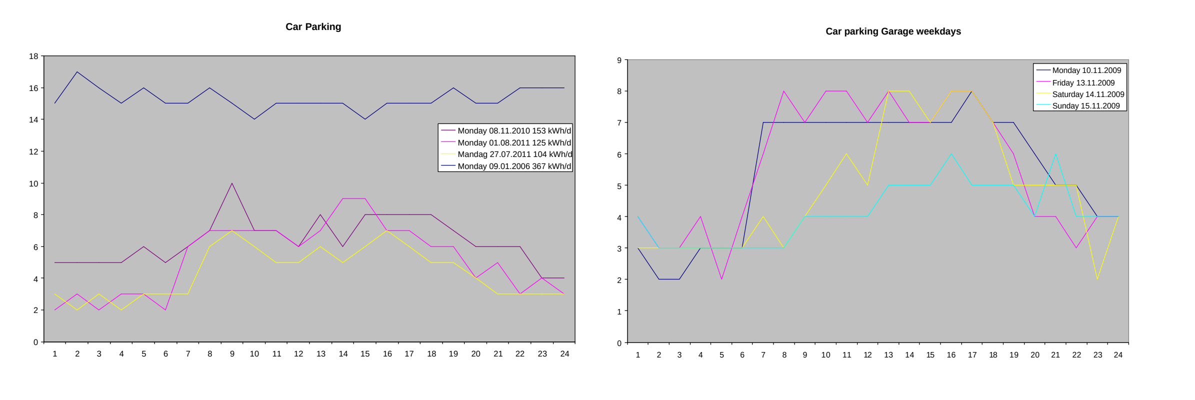


Figure 6 Changes in consumption before and after implementation, all Mondays. Energy performances during weekdays.

As illustrated in the figure above (Figure 6), the baseline situation had a relatively constant consumption (incl. some loads independent of lighting). After implementation one can clearly see the differences between “normal” working days (1st of August) and holidays (27th of July), in addition to daily variation between working/non-working hours.

Going more into details, differences between the weekdays was also registered. One can observe that on Fridays the people leave the office earlier than during weekdays. During weekends, sometimes only the upper floor is active due to people present.

2.2 Constant illumination, a difficult task

In the private/individual offices (approx. 600 rooms) the new 2x28W(T5) suspended luminaires replaced both the old 1x58W(T8) and 1*26 W recessed downlights. The installed power in the suspended luminaires is almost the same as previous, but the lighting quality improved considerably. The old control system was based on manual centralized ON-command in the morning and automatic OFF in the evening, with the possibility to request for an additional period (two hours each time). The calculated LENI values for the two installations were 22 and 6 (kWh/m2 -year) respectively. The calculation is based on measured data for installed power and operational time.

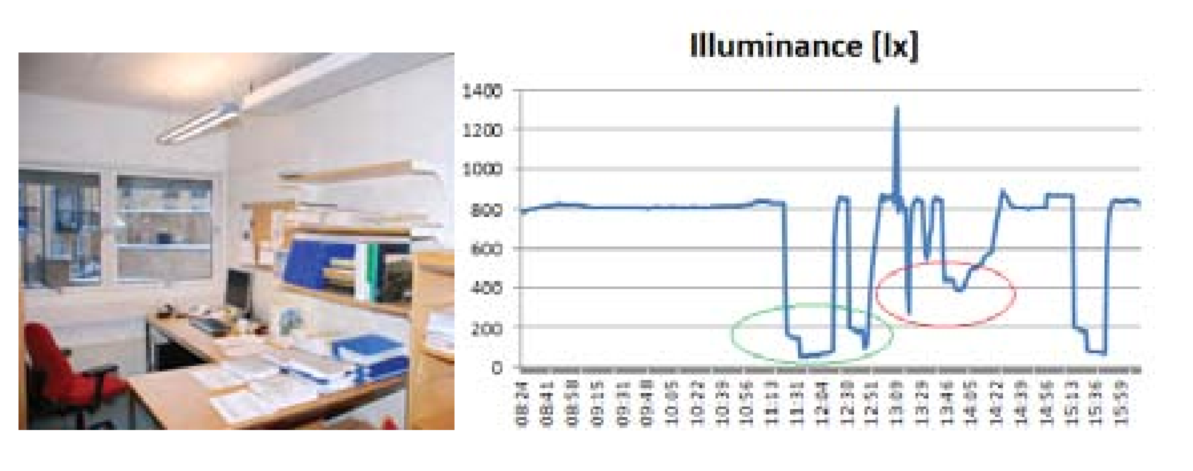
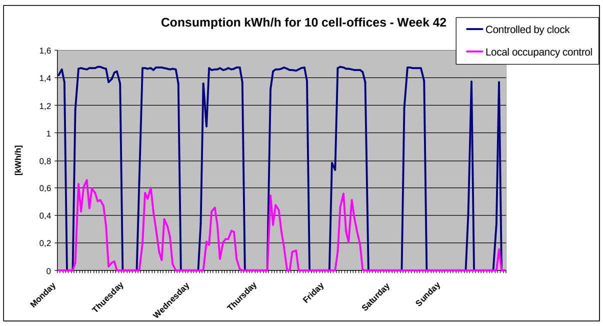


Figure 7 Energy performances for individual offices

The new luminaires are equipped with occupancy detection (Figure 7, green circle) and constant illumination functions integrated into the luminaire. Due to delivery errors, implementation was delayed. During implementation of the constant illumination function, the sensor initiated dimming too early (Figure 7, red circle). This resulted in unacceptably low illuminance levels at the work area, and this function therefore had to be disabled

Based on occupancy detection only, during week 42, the figure below (Figure 8) shows the savings achieved when compared with clock-based control.



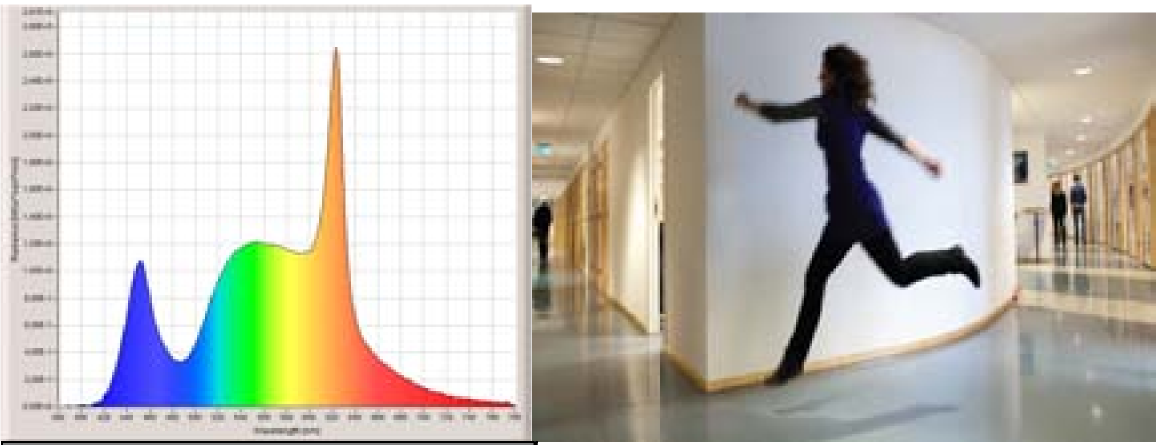
	14 offices, kWh/day		
	Occupancy detection	Clock	Reduction
Monday	9,6	18,2	47 %
Thuesday	8,0	16,9	53 %
Wednesday	8,8	17,0	48 %
Thursday	9,7	22,2	56 %
Friday	8,7	18,2	52 %
Saturday	1,8	4,5	60 %
Sunday	2,1	8,5	75 %
Total	**49**	**106**	**54 %**

Figure 8 Energy performances for individual weekdays

The graph clearly illustrates the situation. Most of the time, the offices are not occupied. The occupant is then either working other places in the building, working outside the premises (consultancy activities) or working from home. The lunch-break can easily be seen most days, as well as the rather low occupancy during the weekend.

2.3 Corridor illumination according to outdoor daylight levels

Installing dimmable LED downlights luminaries in the corridors enables not only dimmed levels during the night, but also dynamical compensation when sufficient daylight is present. The installed luminaries light sources perform gave quite good Ra indexes (Figure 9) under both full and dimmed operation.



	LED 100% power	LED 20 % power
CCT [K]	3516	3563
Ra	89,55	87,53
L [cd/m2]	81100	17300

Figure 9 Measured spectral distributions for chosen LED lamp

Looking more into detail the annual consumption before and after implementation, the following figure (Figure 10) (the main electricity meter) illustrates the change. The figure also includes the dimming of corridor lighting during evening and nights. In general the consumption now rises later in the morning and falls more rapidly in the evening. Much of the baseload on this graph is electricity provided for the data servers and compressors for cooling of the server room.

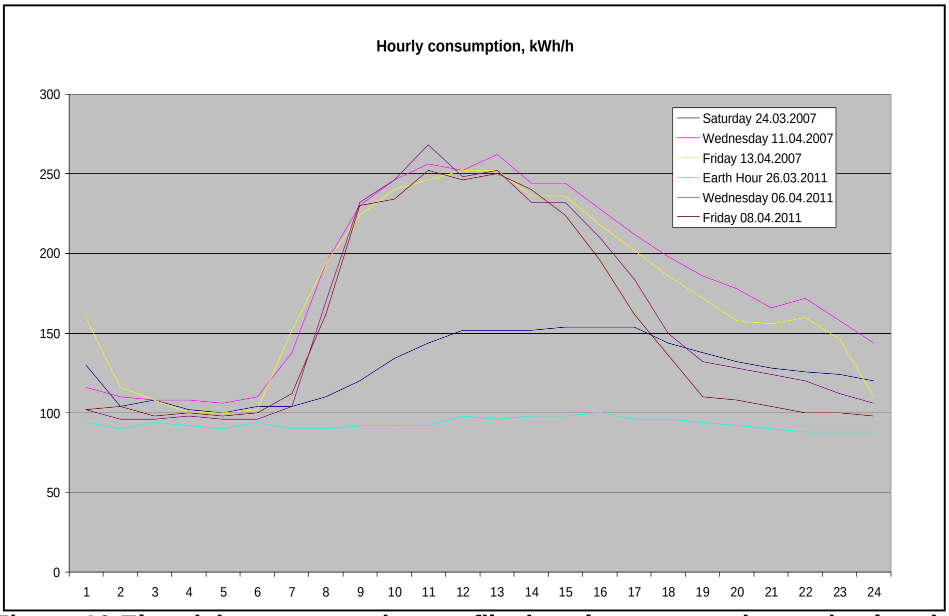


Figure 10 Electricity consumption profile, hourly consumption main electricity meter

3 Correction of savings according to increased heat demand and less cooling

In a larger study made together with the Norwegian lighting association, different lighting technologies were simulated (SIMIEN) [2] and their savings potential was calculated. Utilizing this methodology directly on our case study building, the calculation (Figure 11) showed that the net savings would only be 70% of the total electric saving potential.

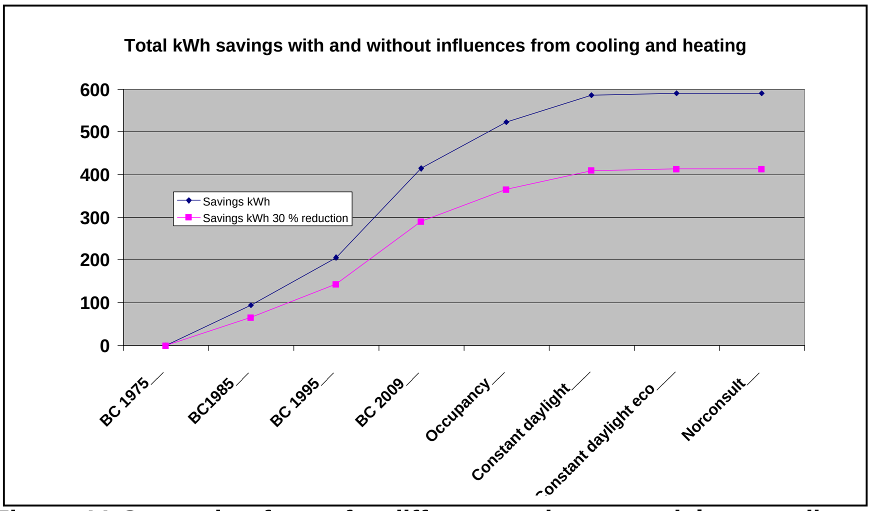


Figure 11 Correction factor for different saving potentials according to building codes

The figure below (Figure 12) gives detailed consumption for the total consumption over 4 years on monthly basis. The most visible changes toward the right of the graph are reduced electricity to HVAC and reduced cooling. Also the consumption of district heating is especially reduced during summer, which influences the cooling needed.

Most of the savings related to lighting measures are found under the category “Main electricity”. This category also includes data-servers, PC/laptops, PC screens and copy machines whose consumption has been increasing due to higher activity levels. This increase makes it difficult to fully quantify the savings from metered data at this level.

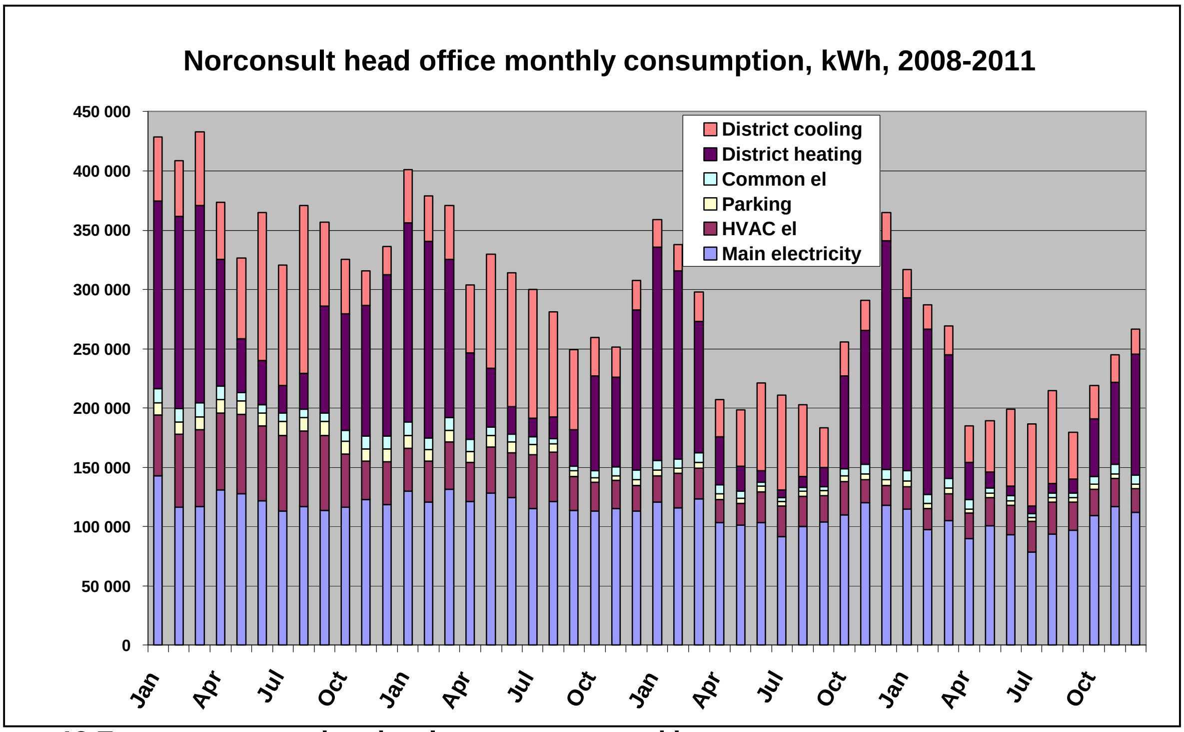


Figure 12 Energy consumption development separated by meters

The consumption is down from 1,45 GWh to 1,02 GWh (adjusted for 0,15GWh to increased consumption for dataservers). The savings represents more than half of the previous consumption.

4 Energy performance certificate

According to the Energy Certificates regulations for buildings in Norway, the 20 years old office building would only gain a **D** score as shown below (Figure 13). A high proportion of the measures undertaken in the project are based on operational savings and savings in technical equipment. This results in minor impact on the theoretical calculation of the building energy performance. Hence any retrofitting of the lighting installation would be favourable. Unfortunately the original installation was rather poor, so the installed power (kW) was not dramatically lowered when retrofitted. Hence the calculation will not affect the given D score, despite quite substantial kWh savings. The theoretical method for energy classification in Norway limits the energy savings which can be claimed from lighting measures. These methods use standardised values which do not reflect the actual activity levels which result in the high actual savings recorded. Hence the building energy class remained unchanged.

In total the savings was 39 %. The figure (Figure 13) is quite conservative as it is not corrected for growth in number of employees and data server capacity during the project period. At the end of the period these served 2100 employees all over Norway, up from 1300 employees, representing a 12.500 kWh/month increase in consumption).

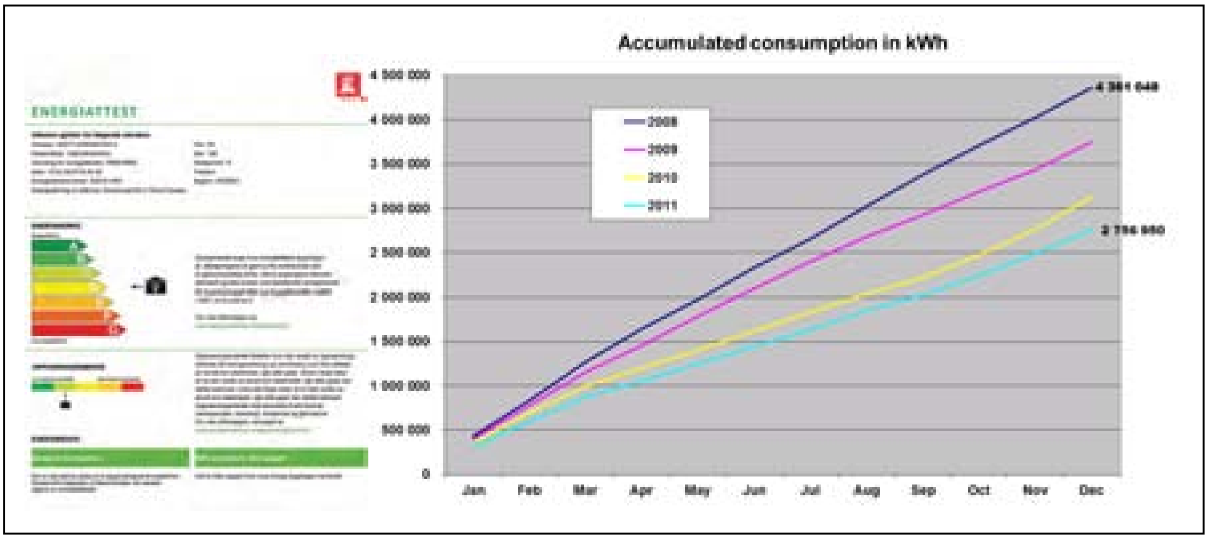


Figure 13 Accumulated energy consumption and the building energy performance certificate

The graph is not corrected for annual day-degrees, which is a measure of heating energy demand due to outdoor temperature. But the year 2008 and year 2011 had almost identical day-degrees.

5 Experience gained

The Energy Efficiency project has resulted in a very high rate, 39 %, of energy saving. Despite the corrections made due to interaction between heat from electric losses for lighting equipment and heating and cooling in general, the overall savings are substantial. Based on the good results and the experience gained, the following guidelines can be offered:

- Constant daylight solutions integrated in the luminaries, given the specific sensor from this project, difficult to implement. The indicative explanation to this is that the sensor design is not fitted for low sun and foggy weather conditions. Occupancy detection works quite satisfactorily and resulted in high saving rates in this case study.

- LED downlights is a very suitable solution, when dimming is easy to utilize

- LED is highly recommended for rooms like toilets and other small rooms

- Occupancy detection should always be considered for lighting installations, and are highly effective especially in closed car park areas (combined with dimming for best savings) and office lighting

- Building Energy Certificates do not necessarily reflect the actual, operational situation

The overall investment in the project was approximately 0,9 million Euros. The simple pay-back period is about 4 years, based on past energy prices and the expected price level.

The lighting quality is improved; the cooling demand during summer is slightly reduced. Generally, the indoor climate comfort has been improved. The problem with constant daylight remains unresolved. But as long as the occupancy detection is so effective, the constant daylight function is of lesser importance.

The factors for occupancy and daylight in the EN-15193 Annex F should be in some way adjusted in the next revision.

The new EN 12464-1 (2011) [3] may give other requirements for vertical luminance levels than used for calculation in this case study.

The project was supported by the governmental energy efficiency fund (ENOVA) as a demonstration project and was completed as such in December 2011 [4]. Some minor measures are scheduled for implementation during the spring 2012. These include some lighting installations, change of pumps and a new cooling device for data server cooling.

Some of the findings in the project are now included in publication no. 19 - “Light and energy consumption” published by the Norwegian lighting association “Lyskultur” [5].

References

[1] EN-15193 Energy Performance for Buildings – Requirements for Lighting, 2008

[2] SIMIEN; Calculation of energy consumption in buildings based on NS 3031 and validated according to NS-EN 15625:2007

[3] EN-12464-1 (2011) Light and lighting - Lighting of work places-Part 1: Indoor work places

[4] Project report; http://naring.enova.no/sitepageview.aspx?sitePageID=1402

[5] Lyskultur Publikasjon nr 19 Lys og Energibruk, 2010

Equipment

Luminance meter: CCD camera from TechnoTeam, Software from LMK Labsoft V. 11.5.2 Classified according to DIN 5032-7B class B. Ra-index measuring tool:

Illuminance metering: Haegner type BC1

Ra and spectral metering/colour temperature: Specbos 1201 2 degrees angel

Energy meters: Various fiscal energy meters; class 2

Lighting control systems in individual offices at high latitude: measurements of lighting conditions and electricity savings

Gentile N. (MSc), Håkansson H. (MSc PhD), Dubois M-C (M Arch PhD)
Lund University, Division of Energy and Building Design, Lund, Sweden

Abstract

This paper presents measurement results of electricity use and lighting conditions in individual office rooms located in Lund, Sweden. The aim is to demonstrate the energy saving potential by using different lighting systems and the satisfaction of users. The measurements are carried out in one empty reference room and four fully occupied test rooms equipped with different electric light control systems. The tested systems include: a presence detector (automatic switch on/off), a manual switch at the door combined with absence detector (automatic switch off), a photoelectric dimming combined with presence detector, and a switchable task light with no ambient lighting except daylight. The four rooms are fully occupied by test persons performing their normal computer-based tasks, and who make a subjective evaluation of lighting conditions in the room and control system once a week. The results for the first monitoring period show that the automatic switch on/off (presence) system is the one yielding the highest electricity use, which repeats earlier simulation results. The photoelectric dimming system which combines a presence detector yields very modest energy savings compared to the presence detector system, a result which contradicts earlier findings but which may be explained by malfunctions and poor sensor position. The room with the task lamp achieves the lowest energy use, which is mostly attributed to the low levels of illumination in the room, which is further confirmed by the test persons. The system with manual switch at the door combined with absence detector achieves the best results in terms of combined low energy use and user satisfaction, and the magnitude of the savings are generally greater than anticipated in earlier simulation studies achieved in the same context.

Introduction

Lighting is an important issue in minimizing overall energy consumption [1]. For the industrialized countries, lighting accounts for 5 to 15% of electricity consumption, while in developing countries, this value may be as high as 86% [2]. In Sweden, lighting accounts for 14 TWh of energy use annually [3], which corresponds to about 10% of total electricity use in the country (146.8 TWh/yr in 2010) [4]. This area offers considerable potential for energy savings [5]. Also, research shows that the most significant environmental impact (90%) of lighting is generated during the operation of the lighting system [3], Moreover, the cost of an electric lighting installation typically represents only 15% of total costs; electricity use during operation of the lighting installation represents around 70% of total costs [6].

In commercial buildings, lighting can represent a large share of electricity use i.e. up to 30-45% [7]. In Sweden, lighting accounts for 25-30% of electricity use in non-residential premises [3, 6, 8]. A recent inventory [8] of energy use in 123 Swedish office buildings indicated that electric lighting is responsible on average for 20% of total electricity use, with an average energy intensity of 21 kWh/m^{2}yr. A recent literature review [9] concluded that this electricity use may be reduced by at least 25% by using simple occupancy switch-off control systems (absence detectors) and by at least 50% using daylight photoelectric dimming. However, these numbers are based mainly on computer simulations and very few measurements have been reported so far. These numbers need to be verified in a real context, with people occupying the buildings and using the lighting controls.

The present study thus aims to fill this gap by reporting the results of in situ measurements carried out in a fully occupied individual office rooms located in the perimeter of the building in the A-building of Lund Institute of technology (LTH), Sweden,. Through in situ measurements in a real building throughout the working year and under normal and realistic working conditions, this study aims to investigate the effect of control systems such as automatic switch-off and daylight dimming on electricity savings in offices, in relation to occupant satisfaction levels.

This study is a part of the Swedish project ‘Energy-efficient office buildings with low internal gains: Simulations and design guidelines’. This project pursues the following objectives:

Previous study on lighting controls

As part of the Swedish project named above, a parametric study was achieved by simulation, using the validated program DAYSIM to examine the relation between office parameters, daylight autonomy and electric lighting consumption patterns as a function of control systems [10]. This study showed that the choice of electric lighting control system generally has more effect on electricity use than the selection of glazing-to-wall ratio (GWR) or orientation, for an individual office room located in the periphery of the building. The study also indicated that the use of an automatic switch-off or so-called absence detector can yield electricity savings of at least 25% compared to a manual switch at the door, for all GWR studied. Furthermore, it was shown that a perfectly commissioned photoelectric dimming system combined with absence detector can yield electricity savings of at least 50%, for all GWR and orientations studied. The study thus concluded that the use of combined photoelectric dimming and absence detector may well be promising for future low energy office buildings. This paper considers individual office rooms with an optimal GWR ratio and aims to juxtapose the previous simulation results with real measurements.

Method

The present study consisted of measurements carried out in four individual office rooms of the A-building located on Lund Institute of Technology's campus (LTH, Lund, Sweden, lat. 56ºN, long. 13ºE). The four rooms, all facing West, had identical sizes and colors and similar furnishings. They were occupied by researchers from LTH, who had a similar sitting position with respect to the window.

Each room had a floor area of 14,5 m^2 (5 m d. x 2,9 m w. x 2,9 m h.) and a glazing-to-wall ratio (GWR) of 30%. The windows were provided with dark coloured rolling screens, which could be manually adjusted by the test persons. The screens' position was recorded in a simple manner by using a scale next to the window and asking the participants to note the height of the screen position on an hourly schedule.

All rooms were painted white and contained bookshelves on both sides, in the vicinity of the window. Opposite the window, a glazed entrance door separated each room from a common circulation corridor. In the rooms, the electric lighting system consisted of two pendant, 120 cm-long direct luminaires placed perpendicular to the window and hanging at 210 cm from the floor. Each lighting fixture contained two T5 fluorescent lamps (28W).

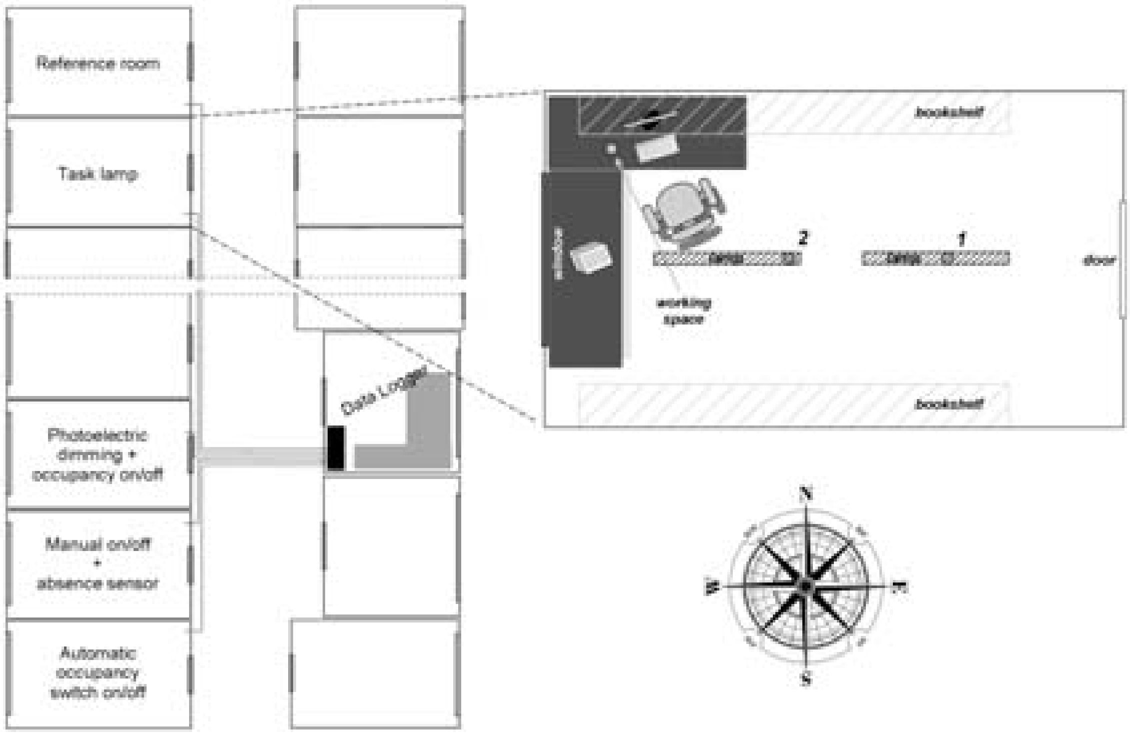


Figure 1. Plan of testrooms

The following control systems were tested with an overall installed lighting power density of 8 W/m^2 (except for the case with only task lamp):

- Automatic occupancy switch on/off (presence detector, delay time of 5 minutes), 2 standard lamps (28Wx2 each), plus a task lamp (LED, 6W);
- Manual switch on/off at the door combined with occupancy switch off (absence detector), 2 standard lamps (28Wx2 each) plus task lamp (LED, 6W);
- Photoelectric dimming, with 2 dimmable lamps (28Wx2 each) combined with automatic occupancy switch on/off + plus task lamp (LED, 6W);
- Task lamp (LED, 6W) only manually adjustable (on/off)

No electric lighting system and no occupant (control room for measuring daylight only).

The monitored parameters in each test room were:

- Electricity use by the lighting system (Wh) with Carlo Gavazzi EM10 DIN Energy Meter, which gives 1000 pulses/kWh;
- Illuminance (lux) at three points in the room: 3,5 m (1) and 2,1 m (2) from the window, both centered from the side walls and at 0,8 m from the floor (fixed points), plus a mobile point on the working desk (Fig. 1). In order to measure fixed points, Hagner SD2 standard lux detectors were used (Fig. 2.a). These sensors were stamped with a calibration constant at around 10 pA per lux and they were connected to shunt resistors on separate connecting boxes according to the individual specifications to give a voltage of 1 • V per lux. The small currents from these sensors at low light levels are at the same magnitude as the currents induced by the 50 Hz power grid in the building. However, if the sampling in the logger is set for an integration time of 20 ms, the disturbance is very effectively cancelled out. The reduction of noise is to approximately 1% of the value with the 50Hz component. The variation is less than a lux with averaging 12 samples. Regarding the mobile desktop point, Hamamatsu S1133 photodiodes with filter were used. The photodiode was mounted in a light ceramic package so no stray light can reach the active area from the side or backside.

Global horizontal illuminance (on roof of the building) was recorded using the Hagner ELV-841 light sensor (Fig. 2.d), while direct/global illuminance on the vertical façade was measured using two Hamamatsu S1133 light sensors mounted on a sheet of metal (Fig. 2.c). One of the sensors was covered by a shading ring to obtain only the diffuse component of the illumination. The direct sunlight was calculated as the difference between total and diffuse illumination. All data was collected every 30 seconds using a Campbell CR1000 data logger, and 6-minutes and 1-hour averages were derived (Fig. 2.b).

The satisfaction with the ambient lighting conditions and control system was assessed by the test persons once a week using a questionnaire. Each occupant experienced each control system for one whole week while performing his/her normal computer-based tasks. Since four systems by four employees were tested, the total length of measurement period was 1 month. The experiment will repeated in different seasons to compare results in different daylight conditions.

The data collection started in November 2011 and thus the paper will present an analysis of the recorded data for the first measurement period.

Figure 2. Data acquisition system: a) luxmeters inside rooms; b) data logger; c) direct/global illuminance on the façade; d) global horizontal illuminance on the roof.

Results

The measurements carried out during the first month (November 2011) represent the starting point for further improvements in the experimental set-up. Despite a series of necessary improvements in the set-up and control systems, this article presents some important results and ideas to further develop the monitoring protocol in the coming months.

Analysis of electricity use of the control systems

The first month of measurement started on November 7th, 2011 and ended on December 2nd, 2011. During the acquisition, some test persons had to leave the room to join conferences or seminars. Some days thus had to be removed from the analysis and a selection of valid days was used for the final data treatment, based on the number of worked hours. Within this selection, the test persons were in the office from 8.00 to 17.00 hours and they left it at most for 20% of the time (lunch break included). Globally, several exterior light conditions were represented in the dataset, since the selected days included sunny days, partly cloudy days and partly intermediate skies. Daily electricity use [Wh] was compiled for each control system; daily average based on these data was calculated and a theoretical annual consumption [kWh/m^2*yr] was derived from these data using:

$$El_{tot} = \frac{El_{day} \cdot n_{wd}}{A_{room}}$$

Where El_{tot} is the total annual electricity use expressed in [kWh/m^2*yr], El_{day} is the average consumption during the observed days [kWh], n_{wd} the number of annual worked days and A_{room} the surface of the room [m^2]. Considering employees work 5 days each week (Mon-Fri) and considering holidays, n_{wd} = 235 was used.

Note that since the annual consumption is derived from daily data measured in the dark November month, we can assume that electricity use is in this way generally overestimated but this statement will be verified by further measurements in the spring and summer 2012.The annual data obtained, which is presented in Fig. 3, is only presented as a means of reference to earlier papers [10], where the discussion about energy savings was based on annual energy use figures.

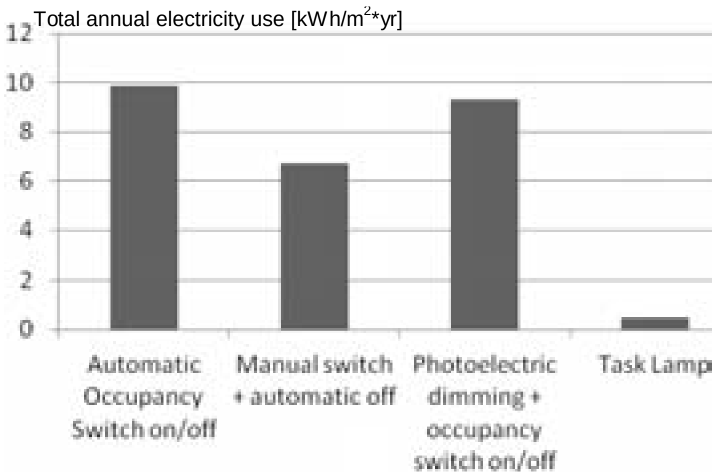


Figure 3. Electric lighting consumption as a function of tested lighting control systems

Fig. 3 shows that the automatic occupancy switch on/off system yields the highest electricity use, a result which was also observed in an earlier computer simulation study achieved as part of the present project [10]. The room with the task lamp yields the lowest electricity use, as expected. The manual switch off combined with absence detector results in electricity use which is about 33% lower than the occupancy switch on/off, which represents larger savings than indicated in the simulation study [10]. Surprisingly, the photoelectric dimming does not perform as well as predicted in the earlier studies. In this case, the derived annual energy use is just below that of the automatic occupancy switch on/off and much higher than in the case of the manual switch on/off by the door.

Note also that although the occupancy switch on/off is the most inefficient system tested, electricity use is fairly low due to the low installed lighting power density ($8W/m^2$).

Regarding the photoelectric dimming system with occupancy switch on/off, several problems explain its poor performance. Electricity use is the second highest between tested equipments (9,33 kWh/m^2*yr) with a saving of only 6% compared to the automatic switch on/off system.In addition, as shown in the next figure (Fig. 4), the correlation between daylight and electric lighting use is not demonstrated. One general problem in this particular system was reported by some test persons: after each movement of the occupants, lamps were automatically turned on at full power and afterwards the intensity was reduced. This caused peaks of electricity use in the system, each time a test person moved in the room. In addition, the built-in photoelectric sensors point towards the floor and the dimmer control adjusts the intensity based on this measurement. Since the floor is dark grey and not very reflective, low illuminance values are 'seen' by the detector, which then adjusts lamp output accordingly to a much too high level. In addition, we noticed that the dimmed lamps seem to be less efficient than lamps with 100% output, since peak consumption is constantly higher than in the other two rooms equipped with standard lamps, probably because of the ballast loss factor.

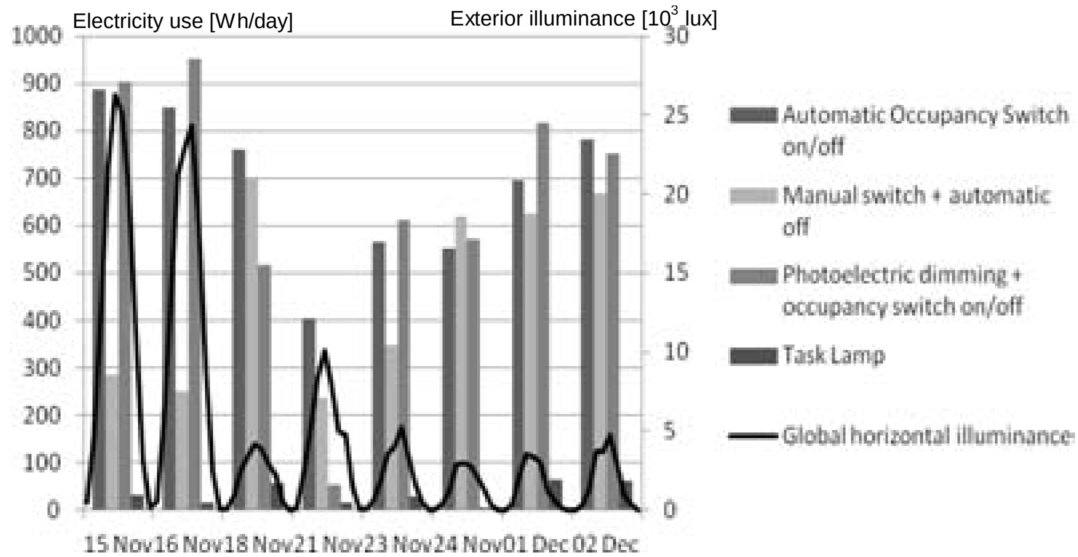


Figure 4. Daily electricity use as a function of electric lighting control system compared to global horizontal/vertical illuminance

Concerning the case with only the task lamp, extremely low electricity use was recorded since a high efficiency task lamp was used. This solution resulted in only 0,49 kWh/m^{2}yr of electricity use, which is 95% less than the automatic occupancy switch on/off system. However, an analysis of the questionnaires by the test persons indicates that the light conditions in the room were quite unsatisfactory, as will be discussed in the sections ahead.

Stand-by losses

A small amount of electricity use was recorded, even during the night due to built features or so-called 'standby' losses. Electricity use during the night was added and divided by the number of hours of monitoring. This calculation allows an evaluation of standby consumption [W] of each control system. The electricity meter's consumption is also included in the values presented in Fig. 5, but it is a negligible quantity.

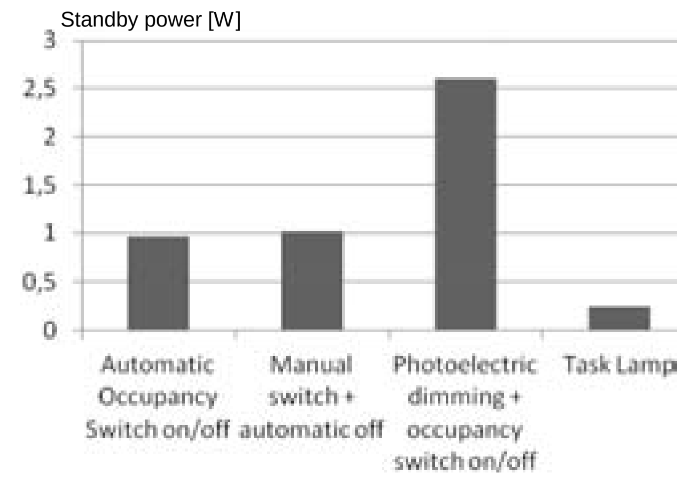


Figure 5. Electricity use in standby condition

Fig. 5 shows that the rooms equipped with the automatic occupancy switch on/off, shows a standby consumption of 1 W, as well as room equipped with the manual switch on/off combined with absence detector. Both rooms have the same type of lamps and energy used by the occupancy sensors is not shown since batteries supplied it. The room with the task lamp had a much lower standby consumption of 0,25 W, due to a small amount of energy used by the transformer. The standby losses of the photoelectric control room was much higher (2,5 W), a difference which can be explained by the more complex sensors in this system. In the last case, indeed, lamps have a built-in occupancy sensor, plus a photodiode with an intelligent system for the self regulation of power intensity based on the environmental illuminance, which requires a certain amount of energy to operate. Thus, during the design of an individual office room, even the probable time of real use of the system should be considered, since in extreme cases, the energy savings could be cancelled out by higher standby losses.

Adaptability of control systems to different daylight conditions

The most important feature of an electric lighting system is to guarantee suitable lighting conditions at the location and time when it is needed, reducing waste and irrational use of energy. The purpose of a photoelectric dimming system is to achieve this result i.e. to provide electric light in compensation of insufficient daylight levels. The next figures (Fig. 6-9) show the relationship between the measured electric light consumption and exterior daylight conditions.

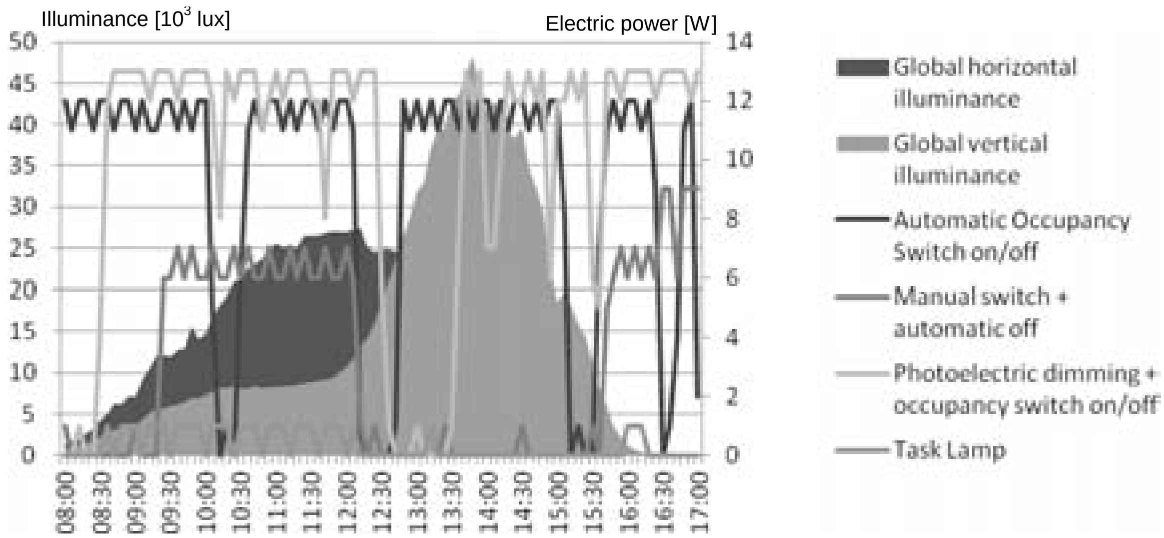


Figure 6. Electricity use during a sunny day (November, 15th), global horizontal and vertical illuminance

Fig. 6 shows that the electricity consumption for the automatic occupancy switch on/off system is constant throughout the monitoring period when an occupant is in the room. There is no regulation according to ambient daylighting levels. The only control concerns switch off during lunch time and morning and afternoon breaks. Fig. 6 also shows that a good correlation is found between exterior daylight levels and electricity use in the case of the manual switch on/off control system. Additional electric light is requested only during the morning when the sun faces the East façade opposite to the test rooms. In the afternoon, daylight is sufficient to guarantee good working conditions indoors and thus, the electric lights are turned off. Global illumination gives a contribution to daylight, but is the vertical radiation on the façade which is dominant in the afternoon on this West facade (Fig. 7.a). In addition, the room's diaries indicate the use of screens limited to around 30 cm at the top of the window, which was enough to cut the direct solar radiation. However, a comparison with the reference room shows that the influence of daylight is still important despite the slightly closed screens and the illuminance in the working space is above 1000 lux during all afternoon.

Interestingly, the photoelectric dimming (Fig. 7d) shows an irregular trend, uncorrelated to daylight levels; which confirms that the system did not work properly; screens were lowered for more than 70 cm during the afternoon with a resulting reduction in illuminance to 700 lux in average in the working space (Fig. 7.b, 7.d).

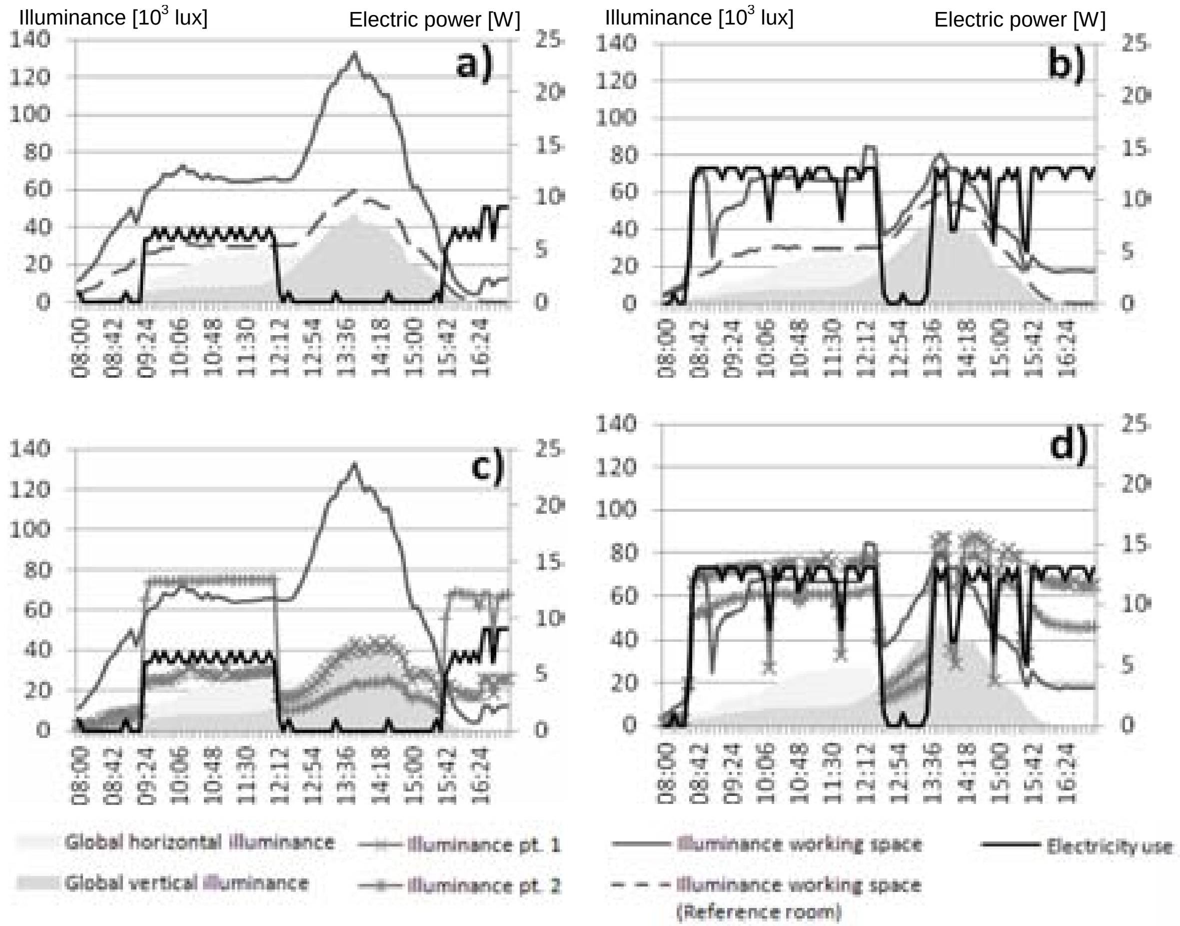


Figure 7. Illuminance levels during a sunny day (November, 15th): a) and c) manual switch on/off, b) and d) photoelectric dimming. Interior illuminance values are multiplied per 100 to compare graphically the relation between interior and exterior illuminance values.

Illuminance values inside the room reveal rather different conditions in the room equipped with the manual control and the one with the photoelectric dimming. The manual switch on/off allows using only one of the two lamps, so occupants generally chose to turn off the lamp closest to the door, since the area at the back of the room was quite remote from the working task area and does not need as much lighting. Higher levels of illuminance closer to the working space are needed (but partially covered by daylight).

During a cloudy day (November, 24th), differences between the systems were less obvious, since all lamps were turned on and a strong regulation was not needed. Peaks in the manual switch on/off room were higher than during the sunny day, most probably due to the additional use of the task lamp, while the ceiling lamp at the back of the room was still turned off (Fig. 8).

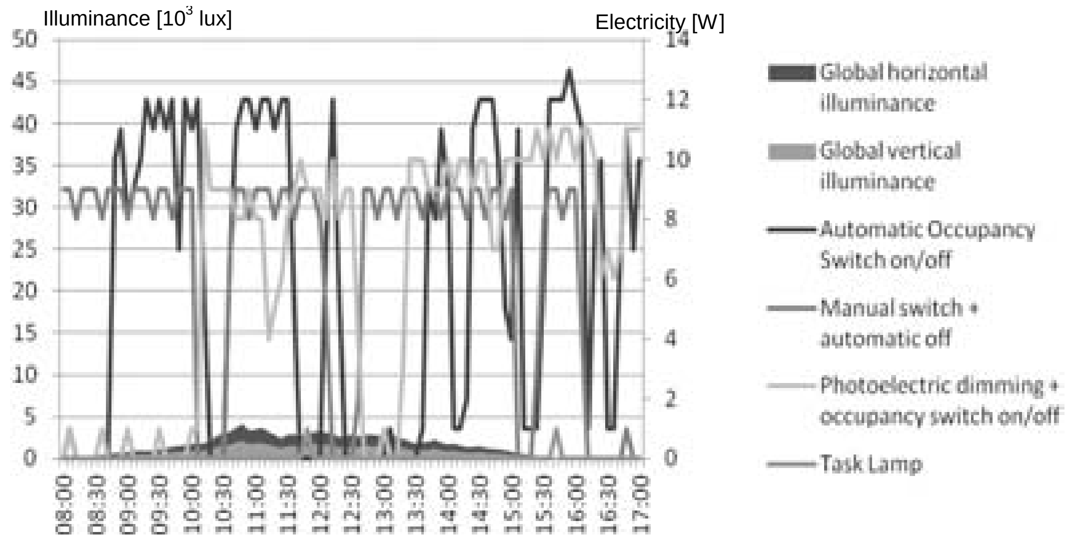


Figure 8. Electricity use during a cloudy day (November, 24th)

Another interesting finding concerns illuminance levels, which were actually lower (even less than 400 lux) on overcast days (Fig. 9.a, Fig. 9.b). Note that this result is in line with previous findings which have indicated no relationship between daylight availability and electric lighting use [11-16] and even higher levels of electric light with higher external illuminances [17]. Begemann, van den Beld & Tenner [17] proposed that occupants could be attempting to balance the brightness of window areas with those of the interior. Thus, under darker overcast sky conditions, the indoor electric light level would be adjusted to a lower average level than under bright exterior sunny conditions.

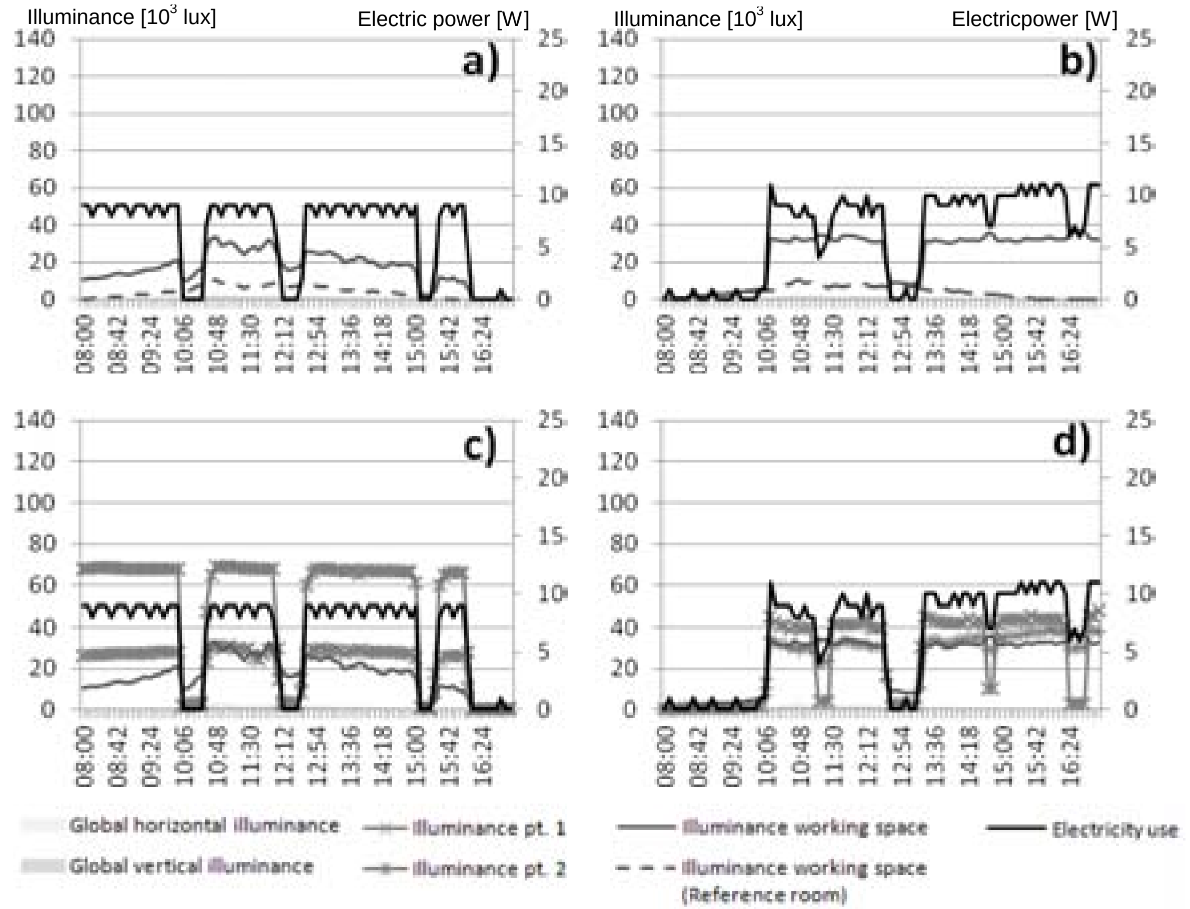


Figure 9. Illuminance levels during a cloudy day (November, 24th): a) and c) manual switch on/off, b) and d) photoelectric dimming.

In addition, we observed that the sitting position of the test person strongly influenced the illuminance in the working area: when it was around 300 lux, illuminance in point 2 reached 700 lux (Fig. 9.c), indicating that the occupant was actually shading his/her own working space (perpendicular and with the back to the ceiling lamp). A preferable condition is shown in the room with photoelectric dimming, probably because on that day, the test person sat parallel to the ceiling lamp (Fig. 9.d).

Occupant's satisfaction
An analysis of the diaries and questionnaires filled by the test persons during the measurements was carried out after the analysis of energy use patterns. The questionnaire consisted of ten questions focusing on satisfaction about the lighting conditions and user-friendliness of the control system. In general, despite small differences in the comments provided by the test persons, the appraisal and evaluation about the different systems tested were are almost all in total agreement.

Generally, test persons did not like the automatic on/off control system, which sometimes even generated eye discomfort (glare) and was considered not flexible since the occupant had no means of adjusting light level or even turning off the lights when light levels were sufficiently high due to daylight. This system resulted in general dissatisfaction, stress and even a decrease in productivity for some of the test persons. Moreover, it was noted that the two automatic systems (occupancy on/off and photoelectric dimming + occupancy on/off) cannot guarantee an appropriate light level in any condition, since for 75% of the sample period, the values were too high and thus, the lighting was glaring, even tiring and distractive. Both automatic systems were considered not attractive and not user-friendly by the test persons, especially the automatic switch on/off.

The manual switch on/off combined with absence sensor was the most appreciated system because of its flexibility. The user could decide simply when to turn the lights on or off and when he/she went for a break, the lights would automatically be turned off upon his/her return, which sometimes allowed subsequent work under daylight alone (and energy savings). No eyes symptoms were reported in this case and the test persons reported a high level of satisfaction for all aspects considered in the questionnaire.

The room with the task lamp was not appreciated either because there was a very insufficient level of lighting, especially at the beginning and end of the day, which are totally dark periods at high latitude in November. The test persons clearly felt in this case that supplementary ambient lighting should be provided during these dark months. While part of occupants reported acceptable light levels around the working space, the entire sample reported that the room was in general much too dark for work and eye symptoms (redness, eye itching, dryness, etc.) were reported. Nonetheless, the possibility to manually control the task lamp was appreciated by test persons, who also said that the system could be successfully used during spring and summer, when interior daylight conditions are favorable. However, note that the questionnaire and measurements both indicate that even at high latitude and during a period with really little available daylight, there were some periods where electric lighting was not needed and a task lamp was sufficient.

Discussion and conclusions

This article presents the results of in situ measurements of illuminance levels and electric light use in individual office rooms with four different control systems for electric lights. The study aims to reveal which system could achieve very low energy use while maintaining suitable level of occupant comfort in a real office context. The second aim was to compare the results obtained for energy consumption with the ones obtained in previous theoretical simulations [10]. This paper only presents the results of the first monitoring period, which occurred during November-December 2011 and will be pursued during the spring and summer 2012. All measurements are performed in the context of Lund, Sweden, a city located at a high latitude (56ºN), where daylight is scarce during the winter and very abundant in the summer. The initial results of the November-December monitoring campaign lead to the conclusions listed below.

Firstly, the overall results of the four different systems, especially for the photoelectric dimming system, clearly differed from the computer simulation results. The photoelectric dimming system, which was combined in this case with an occupancy switch on/off sensor, had relatively high energy consumption, which was just below that of a classic occupancy switch on/off system. In addition, we found that the photoelectric dimming system cannot guarantee occupant comfort since there were many complaints of over lighting. The efficiency of this system could be improved drastically by deactivating the occupancy on/off sensor and replacing it with a manual switch on/off combined with absence sensor. However, despite this possible improvement, the system will still not work optimally in this case, since the analysis has not indicated a good correlation between ambient daylight and electricity use in the considered room. Since the functionality of the ballast and illuminance sensors (both built-in in the lamps) was successfully tested, the remaining hypothesis is that the position and calibration of the illuminance sensor is not appropriate. The illuminance sensor is placed in the bottom part of each lamp and points towards the floor, which in this case was of a dark grey colour with low reflectance. The sensor thus adjusts the electric light output as a function of light reflected from the floor, which reflects only low amount of light. The consequence of this is that the electric light output is generally too high, creating a rather glaring environment for the occupants. This aspect will have to be corrected before the next monitoring campaign is started. Nevertheless, regardless of the cause of malfunctioning of the photoelectric dimming system in this particular case, the measurements still show that good techniques and ideas could be nullified by a bad detail design and lack of knowledge by the installers. Note that in this case, we had someone from the company coming and checking the installation. This is an important factor, which needs to be addressed by engineers, technicians, architects, builders involved in the design of low energy buildings. Additionally, it might be important to change the directionality of the illuminance sensor of the lamp such that it points towards another surface (desktop or wall).

Secondly, this study clearly shows that photometric and electric measurements should be completed by subjective evaluations (questionnaire). In this particular case for instance, the room equipped with the task lamp achieved a great performance in terms of energy savings, but it was considered totally inadequate by the occupants due to much too low light levels obtained, especially at the beginning and end of the day. On the other hand, the occupancy switch on/off achieved the highest electricity use but was also considered inadequate by occupants for two reasons: 1) light levels were too high and the lighting was glaring and 2) the occupant had no possibility to turn off this glaring light, which exacerbated the feeling of frustration with this system.

Thirdly, the relative good results of the classical manual switch on/off system combined with a simple occupancy switch off, show that good performance, both energy- and comfort wise, can be obtained with relatively simple technique. In this case, the occupants were satisfied both with the lighting conditions in the room and the possibility to control the lighting in a very simple way. The possibility to control the light level was one of the issues strongly emphasized by the test persons. Since the working environment is controlled and used by only one person in individual office rooms, this person usually tends to determine adequate light levels (not too dark, not too bright) for her/himself. Most probably, the results would differ if an open working space with several persons was considered instead of individual rooms. In this case, a simple absence detector can be successfully used in order to prevent energy wastage when no one is in the office.

Acknowledgements

The authors thank the test persons who voluntarily participated in this study as well as the following professionals for their useful contributions to discussions during reference-group meetings (in alphabetical order): Åke Blomsterberg (Lund Univ.), Ola Dellson (White architects, Malmö), Katarina Heikkilä (NCC Teknik, Göteborg), Thorbjörn Laike (LTH, Lund, Sweden), Peter Pertola (WSP, Stockholm), Rikard Sjöqvist (Midroc, Malmö), Hans Wetterlund (WSP Environmental, Göteborg). This project is supported by the Stiftelsen för utveckling av Energieffektivt Byggande; CERBOF (Centre for energy and resource efficient construction and management of buildings); SBUF (the development fund of the Swedish Building trade); and NCC Construction Sweden.

References

[1] Hanselaer P, Lootens C, Ryckaert W R, Deconinck G & Rombauts P (2007). Power density targets for efficient lighting of interior task areas. Lighting Res and Technol 39 (2): 171-184.

[2] Mills E (2002). Why we're here : the $230-billion global energy bill: proceedings of Right Light 5, Nice 2002; 369-85, via Hanselaer et al, 2007.

[3] Belysningsbranschen (2008). Upplys Sverige! Rapport om landets övergang till energisnål belysning.

[4] Statens energimyndighet (2011). Energiläget i siffror 2011, retrieved on the web 2012-01-05 at http://www.energimyndigheten.se/Global/Statistik/Energiläget/Energiläget%20i%20siffror%202011.pdf

[5] Govén, T, Bångens L, Persson B (2002) Preferred luminance distribution in working areas. Proc of Right Light 5, May 2002, Nice, France.

[6] Svensson R (ed.) (2010). Ljus och rum: Planeringsguide för belysning inomhus. Andra utgåvan. Ljuskultur. ISBN 91-631-4675-4.

[7] IEA, International Energy Agency (2006). Light's labour's lost: policies for energy-efficient lighting, Paris (France), via Newsham GR, Mancini S, Marchand RG (2008). Detection and acceptance of demand-responsive lighting in offices with and without daylight. Report NRCC-50324.

[8] Statens energimyndighetenen (2010). Energi i våra lokaler. Resultat från Energimyndighetens STIL2-projekt. Delrapport från Energimyndighetens projekt Förbättrad energistatistik i samhället. www.energimyndigheten.se/stil2

[9] Dubois M-C & Blomsterberg Å (2011). Energy saving potential and strategies for electric lighting in future low energy office buildings: a literature review. Energy and Buildings, 43 (2011) 2572–2582.

[10] Dubois M-C. and Flodberg K. Daylight utilization in perimeter office rooms at high latitudes: Investigation of key design features by computer simulations. Lighting Research and Technology. 2012, In press.

[11] T. Moore, D. J. Carter, A. I. Slater, User attitude toward occupant controlled office lighting, Light Research and Technology 34 (3) (2002) 207-219.

[12] T. Moore, D. J. Carter, A. I. Slater, Long-term patterns of use of occupant controlled office lighting, Lighting Research and Technology 35 (1) (2003) 43-59.

[13] J. A. Love, Manual switching patterns in private offices, Lighting Research and Technology 30 (1998) 45–50.

[14] L. Halonen, J. Lehtovaara, Need of individual control to improve daylight utilization and user satisfaction in integrated lighting systems, Proceedings of the 23rd session of the CIE, New Delhi (India), 1995, 200-203.

[15] C. Laurentin, V. Berrutto, M. Fontoynont, P. Girault, Manual control of artificial lighting in a daylit space, Proceedings of the 3rd International Conference of Indoor Air Quality, Ventilation and Energy Conservation in Buildings, Lyon (France), 1998, 175-180.

[16] R. Ashley, J. S. Reynolds, Overall and zonal energy end use in an energy conscious office building, Solar Energy 52 (1) (1994) 75-83.

[17] S. H. A. Begemann, G. J. Van Den Beld, A. D. Tenner, Daylight, artificial light, and people, part 3: visual and biological processes, Proceedings of the CIBSE National Lighting Conference, Bath, 1996, 141–146.

Financial Appraisal of LED Retrofit in Hotels – the Analysis of Depreciated Payback Period within the Organisational Context

Jenny Ya He[1], Peter Guthrie[1] and Douglas Crawford-Brown[2]

[1]Centre for Sustainable Development,
University of Cambridge

[2]Cambridge Centre for Climate Change Mitigation Research,
University of Cambridge

Abstract:

Light Emitting Diodes (LEDs) have received increasing adoption in commercial buildings, yet there has been little rigorous analysis of the systematic costs and benefits of installing LEDs. This research illuminates the financial costs and the motivation and barriers of LED retrofit through in-depth case-study analysis of one major international hotel chain. The work is composed of two parts: investment appraisal of lighting retrofit projects, which forms the core financial foundation of the LED project; and analysis of the decision-making process embedded in the organisational structure of the hotel. The research develops an LED investment appraisal model which takes into account the product cost, engineering cost, and the operational cost of LED projects. It is found that LED investments represent a highly attractive investment proposition due to its short depreciated payback period (DPP). However, the decision-making for LED investments is complicated by the rapid development of LED products, and their technical compatibility with the existing lighting system. The research portrays a comprehensive picture of making decisions for lighting retrofit in hotels, which has further implications for understanding the motivation framework and deployment and adoption of energy efficient technologies in the built environment.

Keywords: LED retrofit, financial appraisal, depreciated payback period, decision-making process, hotels

Introduction

Lighting consumes approximately 19% of electricity globally [1]. It is estimated that by switching to more efficient light bulbs, the US alone can achieve an accumulated savings of $250 billion over 2010-2030 at today's energy price [2]. Light Emitting Diodes (LEDs) represent growing opportunities for energy efficient lighting - by 2030, LED lighting is expected to grow to 74% of the US lighting market (in lumen-hours) [3].

One important area of LED application is the commercial sector. The professional channel is regarded as having the most potential for early lighting technology adoption [4], and hotels in particular have seen an increasing adoption of LEDs [5]. Hotels offer an interesting context to examine LED applications, as hoteliers respond to both the economic benefits and aesthetical features and reputational gains of LEDs [5].

Despite the growing adoption of LEDs, there has been little research on the rationale underpinning LED lighting upgrade. One predominantly used tool which forms the economic foundation of decision-making is financial appraisals. The financial appraisal of LEDs poses several challenges: one is the choice of the appropriate financial appraisal model suitable for LEDs; the other is determining the scope of cost-benefit analysis in the actual implementation of the model. There are several financial appraisal models used for the analysis of building retrofits:

NPV, payback period, internal rate of return (IRR), depreciated payback period (DPP), cost of conserved energy (CCE), etc.

The cost-benefit analysis of LEDs is complicated by the rapid development of the technology. There are a wide diversity of LED products with varied technical performance and engineering features [5]. Therefore, there can be significant cost entailed in purchasing additional lighting accessories and installing the systems such that it is compatibility with the existing lighting system.

This research investigates the cost-benefits of LED retrofit by examining a retrofit programme across one international hotel chain. The methodology used is case studies. Data is collected from chief engineers and energy managers through site visits, interviews (both group and individual), and previous project documents.

An appropriate financial appraisal framework for hotel lighting retrofit project is developed through analysis of different project investment appraisal models. By situating the quantitative financial analysis within the context of decision-making in hotels, the research reveals how financial appraisal tools are used in real investment contexts. In doing so, the study illuminates the real motivation behind LED lighting projects, which has implications for future deployment of LEDs in buildings.

Literature Review

Due to the novelty of LED technologies and the short history of LED application in buildings, the financial (and lighting performance) assessment of LEDs in academic research has so far been limited. Financial assessment of more conventional energy efficient lighting projects (e.g. using fluorescent) is more mature, but these earlier assessment frameworks do not fully accommodate the specificalities of LEDs.

In this section, several predominant financial appraisal methods for appraising retrofit projects are examined. For LED retrofit projects, the cost factors are intrinsically related to the engineering implications of the technology.

Financial Appraisal of LED retrofit projects

One of the most comprehensive project-level assessments of LED retrofits is the *lighting demonstration project* conducted under the U.S. Department of Energy (DOE) GATEWAY Demonstration Program[1]. A total of 16 project assessments have so far been carried out since October 2009. One of which is a 'Demonstration Assessment of Light-Emitting Diode (LED) Retrofit Lamps at Intercontinental Hotel in San Francisco, CA [6]. The financial assessments are based on the National Institute of Standards and Technology's Building Life-Cycle Cost (BLCC) software, which is a Building Life-Cycle Cost (BLCC) Program developed by the National Institute of Standards and Technology (NIST) to 'provide computational support for the analysis of capital investments in buildings'[2]. For more general energy efficient lighting projects, the Chartered Institute of Buildings Service Engineers (CIBSE) offers a relatively comprehensive framework for the financial appraisal of lighting schemes [7]. However, the cost analysis is relatively simple and is based upon the reference of earlier energy efficient lighting technologies.

The financial assessments of more conventional energy efficient lighting systems is represented in the work Mahlia, etc [7] [8]. Others [9] [10] conduct economic analysis of lighting as part of an overall appraisal of various energy saving measures in buildings.

Financial Appraisal Models

---

[1] http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html

[2] http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc

Drawing from past research, there are five financial criteria commonly used in investment appraisals for energy efficiency retrofit in buildings: the net present value (NPV), internal rate of return (IRR), Savings to Investment Ratio (SIR), cost of conserved energy (CCE) and payback period [12] [10] [13]. NPV equals the 'present value of annual free cash flows less the investment's initial outlay [14]'. Whereas IRR is 'the discount rate that equates the present value of the project's future free cash flows with the project's initial outlay [14]'. CCE is cost of saving each unit of energy through the energy efficiency refurbishment. It has been promoted by researchers such as Feist [15] [16], Krause and Koomey [17], Martinaitis [18], etc. and is adopted in Germany as the underpinning model to assess the economics of thermal renovations supported by German government policies [19].

The payback period is the most straight forward method out of the four, and is used extensively in industry and in commercial environments. The payback period indicates 'the number of years required to recapture the initial investment [14]'. However, compared to NPV, the indicator fails to take into account the value of the investment exceeding the payback period or over the life time of the project.

Two critical issues arise from the use of these different models: one is the consideration of the time value of money, or the financing cost; the other is incorporating the fluctuation in future energy price, which is critical to the economics of energy efficiency projects. NPV and CCE naturally incorporate a capital interest rate through the discounting of cash flows and the annualisation of the upfront capital, respectively. The simple payback period, however, does not. A more comprehensive payback period method called the Depreciated Payback Period, or the Discounted Cash Flow Payback Period, has been developed, which takes into account the time value of money [10] [12]. Both the CIBSE framework and the BLCC software offer Depreciated Payback Period indicators as outputs.

The fuel price inflation rate is rarely been incorporated in energy-saving financial models. The DOE BLCC software, for example, uses the US national average retail price of electricity as a reference point, and adjusts the electricity price according to the specific region the project is located [6]. Those appraisals which do take into account the rise of fuel price are represented in the work of Helcke [11], Gavin [19], and the German building renovation assessment model.

Scope of Cost-Benefit Analysis

The free cash flow in energy efficient lighting projects derives from the cost savings of owning and operating the new lighting installations as compared to that of the existing system [6]. The main components of the cost of ownership and operation consist of initial up-front capital cost, energy cost and maintenance cost. CIBSE, DOE BLCC, etc each offer a structure to assess the economics of an LED project, however, none is comprehensive. CIBSE fails to take into account the affect of dimming on energy consumption. The labour cost of relamping does not differentiate between group relamping and spot relamping. In the BLCC framework, the cost of control gears is not factored in the initial cost; neither is power factor mentioned in the energy cost. For both frameworks, the initial install cost is counted as one block cost, however, the engineering intricacies of LEDs can result in varying install requirements. Neither do the two frameworks take into account the savings on gear replacement during maintenance.

In all, there is very little representation of the process and intricacies of LED lighting upgrades in the economic assessments. Financial assessment frameworks do need to take these factors into account, as the engineering implications of installing and maintaining LEDs can significantly affect the cost-benefit analysis.

Past research on financial appraisal of energy efficiency projects are mostly separate from the decision making process of the investment. In effect, it assumes the ultimate rationality of the decision-makers to make choices based on the results of the economic analysis. While cost-benefit assessments form the foundation of investment decisions, economic analysis are based within the human context of decisions. It is equally important to understand the role of investment appraisals in the retrofit process, and how stakeholders make use of the tool.

Research Methodology

Case study methodology: In order to gain a 'detailed understanding of the contexts and settings of' making investment decisions for energy efficient lighting retrofit, and to reveal the details of the true costs and benefits of upgrading to LEDs, the study adopts a case study methodology. The case study approach will be able to expose the engineering implications of LEDs and how they affect the financial appraisal.

The study chose one major hotel chain in the UK as a subject of analysis. The hotel chain rolled out a lighting retrofit project across all of its estates, including restaurants and hotels. The researcher carried out 8 semi-structured interviews, roundtable discussion with major stakeholders, and a fieldtrip to one of the lighting trail sites. The project documents were collected from the hotel chain sustainability/energy manger, chief project manager, electrical contractors. More detailed lighting technology data were compiled from lighting wholesalers and lighting manufacturers.

Financial Appraisal Model

The research adopts the DDC model discussed by Au & Au [12], Nikolaidis et al. [10], and Galvin [19]. The model and relevant parameters are demonstrated below:

$$\mathrm{DPP} = \frac{-\ln\left(1 - \frac{p \cdot C}{Ft}\right)}{\ln(1+p)} \tag{1}$$

where C is the initial investment, Ft is the current net cash flow from the project in year one, and *p* is the combined discount rate which takes into account the inflation of energy price:

$$p = \frac{1+d}{1+e} - 1 \tag{2}$$

where *e* is the annual percentage increase in fuel price, and *d* is the cost of capital. Note that p is applied to entire net cash flow, although strictly speaking only the energy savings are subject to the energy price inflation rate E.

To differentiate between maintenance savings M and energy savings E, the model for the differentiated payback period should be T:

maintenance savings M and energy savings E, the model for the differentiated payback period should be where t:

$$\frac{\mathbf{E}}{\ln(1+\mathbf{p})}(1+\mathbf{p})^{t} + \frac{\mathbf{M}}{\ln(1+\mathbf{d})}(1+\mathbf{d})^{t} = \frac{\mathbf{E}}{\ln(1+\mathbf{p})} + \frac{\mathbf{M}}{\ln(1+\mathbf{d})} - \mathbf{C} \tag{3}$$

Scope of Cost-benefit Analysis

The scope of cost-benefit analysis is mainly composed of the initial capital cost of the project and the operating cost savings of the new lighting system. The scope of the initial capital cost (Table 1) is based on the synthesis of the CIBSE and BLCC framework.

Table 1. Initial Cost Components for LED Lighting Projects

Initial Capital Cost	Cost of luminaires
	Cost of lamps

(C)	Cost of accessories
	Cost of installation

The calculation of the initial capital cost is complicated by the intricacies of LED technologies. LED replacement lamps may have a lower lumens output compared to the lamps they are supposed to replace, and more fittings are sometimes needed which would increase the up-front capital cost of the project [5]. Furthermore, the old fixtures may not suit the directionality of LED lights or meet their stringent heat management needs, therefore old light fixtures may need to be replaced with purposefully designed LED fixtures, further increasing capital cost [5].

Another issue pertains to electrical compatibility: LEDs replacement lamps may not function with the existing electrical system, especially old transformer and control units, and new lighting accessories are often needed. The associated engineering cost can be far more complex than simply relamping, and often, re-wiring and taking-down ceiling tiles may be needed.

The Operating Cost Savings (O) are composed of the free cash flow Ft derived from energy savings and maintenance savings from running the LED system, as opposed to the traditional system [7]. The components of the operating cost and various influencing factors are displayed in Table 2.

Table 2. Free Cash Flow Components for the LED Lighting Projects

			Influencing Variables
Operating Cost (O)	**Energy Cost**		Lamp Watts
			Lamp Qty
			Lamp Operating Hours
			Dimming Factor
			Power Factor
			Energy Price Variation
	Maintenance Cost	**Maintenance Capital Cost**	Cost of Lamps
			Cost of Accessories
		Maintenance Labour Cost	Group Relamping
			Spot Relamping

The major operating cost savings of LEDs derive from their low wattage and their much longer lifetime compared to conventional technologies. Within the total energy cost, dimming factor effects both energy consumption and lamp lifetime. The effects are demonstrated in the wattage multiplier and the life time multiplier [6], which is respectively the percentage of wattage consumed against the total wattage when operating in full lumens, and the percent increase in lamp lifetime due to dimming. For LEDs, the extent that can be dimmed is limited compared to conventional technologies, so the LED system may consume more energy compared to old lamps [5]. LED maintenance cost is much lower in terms of lamp cost and relamping labour cost. In hotels, relamping can form a crucial part of the overall operating cost [6].

Findings and Discussion

Project description

This study examines a major hotel chain in the UK applying the cost-benefit framework above. Hotel A is the UK's largest hotel brand, with over 40,500 rooms and more than 600 hotels. The hotels are owned and operated by Hotel Group A, which is a FTSE 100 organisation headquartered in the UK, and owns hotels, coffee shops and restaurants. The Group has five different restaurant brands.

In 2009, the hotel group launched their corporate responsibility strategy, which, amongst others, aims to reduce relative operational carbon emissions by 26%, compared to a 2009 baseline by 2020. As part of the programme, a £7m sustainable refurbishment programme of the group's building stock was initiated in 2010, of which £2.6m was spent on energy efficient lighting retrofit. A further £3m was invested in lighting upgrades in 2011.

LED Technology and Initial Capital Cost

The incumbent and replacement lighting technologies used in the retrofit of the restaurants are illustrated in the table below:

Table 3. Incumbent and new replacement lighting technologies

Incumbent Technology	Replacement Lamps
240V 50W GU10	240V 7W LED GU10
240V 35W GU10	240V 3W LED GU10
240V 35W AR111 spot	240V 7W LED AR111 spot
12V 35W MR16	240V LED GU10

In the choice of lighting technologies, the Project Manager did not opt for a like-to-like replacement for all existing lamps (e.g. Halogen MR16 to be replaced by LED MR16). Mains voltage LED GU10 was chosen to replace low voltage MR16 instead of mains voltage LED MR16. The Energy Manager explained that this would avoid the complexity of having to adapt the low voltage LEDs to existing transformers, as low voltage LEDs are sometimes incompatible with the existing control system, and would have required changing new ballasts and transformers. The technologies chosen were also non-dimmable to avoid problems arising from LED compatibility with dimmers.

The choice of technology reflects the unstable performance of latest LED technology. Compatibility with the existing electrical system and dimmability pose a real issue in LED retrofit, and experienced engineers circumvent the problems wherever possible.

According to interviews, the comparable lux level of the LED lamps was not an important selection criterion, because 'matching lux level was not paramount' for the hotel ambience. Other lighting criteria such as colour temperature and beam spread were however crucial to creating 'the right ambience'.

Thanks to the Project Manager's intelligent selection of LED technologies in this project, no ballast, controls, dimmers, transformers were needed. This reduced the initial capital outlay and future maintenance hassle. The old fixtures were re-used with some additional re-wiring work.

A significant installation cost – around 120% of the capital cost of the lamps – was incorporated in the cost-benefit calculations of the financial appraisal. The installation cost was composed of around 20% of accessory cost (e.g. cost to replace broken fixtures), while the rest was labour cost. Given the nature of the restaurant/hotel business, a lot of installation work took place out-of-hours, thus greatly increasing the cost of the installation. The engineering work was out-sourced to external electrical contractors. Some rewiring work was required to switch from low voltage to mains voltage lamps.

According to financial calculations, the total up-front cost of retrofitting restaurant lighting to LEDs amounted to £590,810 across the entire group. This represented 375 projects in total, with an average spending of £1,575 per project. The lamp cost amounted to £268,550, while the installation cost, including engineering labour cost and additional accessory cost summed up to £322,260.

Operating cost

The operating cost of a lighting system is composed of energy cost and maintenance cost. Financial appraisal reveals that before the retrofit, the lighting system consumed 4,115,605 kWh, which equals £411,560 under current energy tariffs at £0.1 per kWh. After switching to the LED system, a reduction of 73.5% in total energy consumption was achieved, totaling £107,989.

Comparison of technology specifications reveal that the LED products chosen in the project have an average lifetime of 50,000hrs, or 8 years running at 6500 hours per annum, compared to 3,500hrs, or half a year, for the incumbent halogen lamps. The longer lifetime of LEDs means that the frequency of replacing burned-out lamps is greatly reduced, thus also reducing the maintenance cost. According to the Energy Project Manager of the hotel group, lighting maintenance is carried out on a spot-relamping basis in the restaurants. On the larger sites, an engineer is employed full time to deal with maintenance issues, and relamping costs £2.5 per bulb; on the smaller sites, electricians are called in when lamps go out. Because most lighting-related maintenance takes place overnight, the cost amounts to £35 per bulb. Presuming 50% small sites and 50% large sites, the average labour cost of spot-relamping costs £18.8 per bulb.

Results from the model show that the operating cost for the old system is £1,190,968 per annum, with 65.4% attributed to maintenance cost. After the retrofit, the operating cost is reduced to £227,912, representing a 80.8% decrease, of which 52.6% is attributed to maintenance.

Depreciated Payback Period (DPP)

DPP is calculated using equation (1). Figure 1 displays the effect of energy price inflation on DPP, when capital cost is set at 7.5%[3]. It is shown that starting from the current energy price baseline of £0.1 per kWh, when energy price inflation rate increases from 0-1, the depreciated payback period decreases from 0.65 years (around 8 months) to 0.40 years (around 5 months), representing a 38% reduction. According to interviews, a DPP within one year represents a highly attractive investment to the hotel chain.

[3] The hotel did not provide any number on their internal discount rate, therefore 7.5% was chosed based on that used in the DOE Assessment [5].

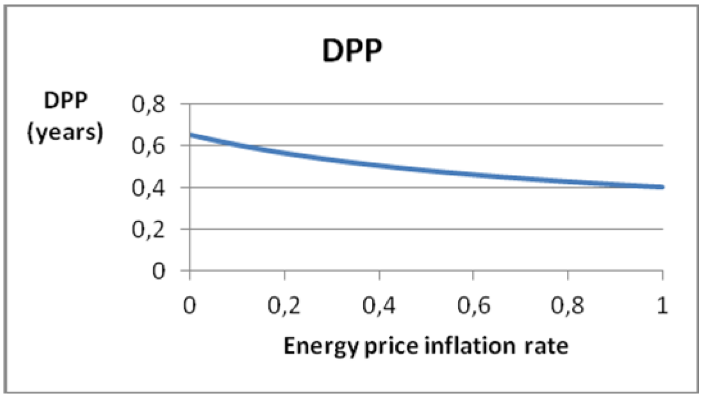


Figure 1. Impact of energy price inflation rate on DPP, when capital cost is set at 7.5% and baseline energy price at £0.1 per kWh

Figure 2. displays the effect of capital cost on DPP. Energy inflation rate is kept constant at 0.025, whereas capital discount rate ranges between 0.05 to 1. DPP increases with capital cost, and rises to 1.3 years (16 months) at an interest rate of 100%. This represents a 109% increase from the base line DDP of 0.625 years (8 months) when interest rate is 0.05.

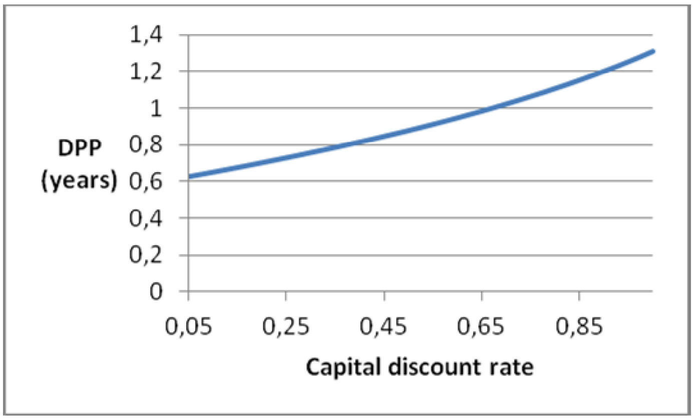


Figure 2. Impact of capital cost on DPP, where energy inflation rate is set at 0.025, starting from a baseline of £0.1 per Kwh

Overall, comparing Fig.1 and Fig. 2, capital cost has a more significant impact on DPP compared to energy price inflation. This can be attributed to the current low baseline energy price in the UK, which exerts little influence on DPP when energy price increases.

The detailed description of the individual cost items are displayed in the Appendix.

1.1 Decision-making Process

The decision-making for energy efficient lighting lies within a broader MAC (Marginal Abatement Cost Curve) analysis conducted by the hotel group in early 2006. The MAC analysis identified the cost and benefit of different energy efficiency strategies, and different projects of short and long payback periods were bundled together for an investment cycle in one financial year, to achieve an overall payback period hurdle of around three years. Lighting represented the shorter payback options, and was bundled with longer term projects, such as water recycling, etc. The overall lighting retrofit programme was therefore phased across different financial years.

The first phase of the lighting programme targeted restaurants, including Brewers Fayre, Beef Eater, and BarEst, as restaurants represented the quick-win sites, due to the low quality of the existing lighting technologies. Retrofit for hotels were only initiated in late 2011, through a hotel corridor demonstration project.

All costs were financed internally out of group's maintenance budget CAPEX. Sign-off is required depending on the total cost of the investment. The hierarchy of decision-making constitutes of the Operations Director, Energy Department Director, and ultimately the Investment Committee.

Impact of Financing

As explained earlier, financial considerations affected how the lighting programme was planned and phased. Lighting was matched with other projects; and, within the overall lighting projects, the quick-win restaurant sites were selected first to assess the real cost and technical performance of the technologies. A trail of around 10 restaurants was carried out before the roll-out.

Finance also affected the choice of LED lamps instead of LED luminaires, which was mostly due to financial concerns: the latter were much more expensive than the former. However, this results in several problems: the old fittings are not optimised to support the lighting characteristics and heat-exchange demands of LED lamps [5]. Engineering wise, the old fixtures used for low-voltage lamps needed to be rewired to support mains voltage lamps [5].

The significance of finance is also reflected in the strategy to switch from low voltage lamps to mains voltage lamps. Mains voltage lamps avoids the cost of upgrading existing lighting accessories to enable compatibility with the new lamps, and also reduces the maintenance cost for these components.

Other Influencing Factors

In the decision-making process, the importance of ambience is reflected in the important role played by the marketing team in the choice of technologies. After the manufacturers installed the technologies in the pilot project, it was up to the marketing team to decide upon the ultimate scheme mainly based on aesthetics. Amongst the myriad of LED lamps under the same lamp type (e.g. LED GU10), the marketing team had the final say on the technology based on aesthetic standards.

Conclusion and Further Research

The paper presents the economic aspects of an LED retrofit project in a major hotel chain based within the organisational context of decision-making. The research stems from the need to understand the rationale and cost-benefits of LED projects amidst an increasing trend of LEDs application in buildings. The work represents one of the first few analyses of LED projects to integrate the financial appraisal within the human context of decision-making.

The study develops a systematic framework to calculate the cost-benefit of a lighting retrofit throughout its lifetime. The framework incorporates the up-front cost of the lighting equipment and the more complex engineering cost, labour cost, and additional accessory cost of the project. The Depreciated Payback Period (DPP) is chosen as the metric of analysis. The metric takes into account the industry norms of using simple payback period, whilst incorporating the time value of money. In this study, the inflation of energy fuel price is further integrated within the model. It is found that the DPP for LED lighting retrofit is extremely small - less than one year. Rise in capital cost has more impact on DPP compared to the inflation of energy price, given the extremely small base value of current energy price. The cost of engineering represents a significant portion of the overall capital cost of the project, which is mainly due to the high labour cost of out-of-hours installation in the context of the hotel.

In the decision-making process, DPP plays a critical role in determining whether retrofit projects are invested, and the allocation of finance. LED lighting retrofit lies within a larger energy efficiency investment programme across the hotel chain. LED projects were bundled with other investment projects with longer DPPs to achieve a certain payback period for each investment cycle in one financial year.

Financial considerations played a critical role in the planning and phasing of the lighting retrofit, and the selection of lighting technologies. An LED lamp upgrade was chosen instead of LED luminaire upgrade mainly due to the cheaper price of LED lamps, despite the better performance of LED luminaires as a system.

The study reveals the intricacies of LED application, and presents an interesting example of how a rapidly developing energy efficiency technology is adopted in practice. The chief engineer adapted to the uncertainty of LED performance in terms of compatibility with the existing lighting system (e.g. transformers and dimmers), by choosing low voltage non-dimmable lamps instead of mains voltage lamps. This choice avoided much of the engineering work and capital costs associated with ensuring the new LEDs are compatible to lighting accessories.

Due to the lack of data, there is little information on what constitutes the majority of engineering cost of the project, which amounts to 150% of the lighting equipment cost. The focus of this paper is mainly on the economic calculations of a lighting retrofit project, therefore the decision-making process of stakeholder interaction is not elaborated. The context of decision-making is explained only to the extent of how the process is phased, planned, and how the technologies are chosen. However, given the importance of finance in the LED retrofit project, future work needs to examine in more detail the process of making of financing decisions, and the potential of non-conventional financing mechanisms in overcoming the financial restrictions of LED retrofit. In addition, work needs to be conducted to understand how LEDs are implemented in commercial environments with varying ownership and operational structures, to reflect the complex environment of the hotel industry.

References

[1] International Energy Agency. *Light's labour's lost: policies for energy-efficient lighting*. Paris: International Energy Agency and Agence Francaise de Developpement, 2006.

[2] Department of Energy. *Energy savings potential of solid-state lighting in general illumination applications*, 2012. Can be downloaded at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl2012_energysavings_factsheet.pdf.

[3] Department of Energy. *2010 U.S. Lighting market characterization*, 2012. Can be downloaded at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

[4] Department of Energy. *Compact fluorescent lighting in America: lessons learned on the way to market*, 2006. Can be downloaded at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf

[5] He J.Y. *Facilitating Energy Efficiency Lighting in Hotels through Acceptable Financing Mechanisms*. University of Cambridge Dissertation, 2012.

[6] Department of Energy. *Demonstration assessment of light-emitting diode (LED) retrofit lamps at Intercontinental Hotel in San Francisco*, CA, 2010. Can be downloaded at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_intercontinental-hotel.pdf

[7] Chartered Institute of Building Service Engineers. *Code for lighting ([16th ed.] ed.)*. Oxford: Butterworth-Heinemann, 2002.

[8] Mahlia T.M.I., et al. *Cost-benefit analysis and emission reduction of lighting retrofit in residential sector*. Energy and Buildings, Volume 37, Issue 6, pp 573-578, 2005.

[9] Mahlia T.M.I., Abdul Razak H., Nursahida M.A. *Life cycle cost analysis and payback period of lighting retrofit at the university of Malaya*. Renewable and Sustainable Energy Reviews, Volume 15, pp 1125-1132, 2011.

[10] Nikolaidis Y., Pilavachi P.A., Chletsis A. *Economic evaluation of energy saving measures in a common type of Greek building*. Applied Energy, Volume 86, pp 2550-2559, 2009.

[11] Helcke G. *The energy saving guide*. Oxford, England: Pergamon, 1981.

[12] Au T., Au T.P. *Engineering economics for capital investment analysis*. Newton (MA): Allyn and Bacon, 1983.

[13] Martinaitis V., Rogoza A., Bikmaniene I. *Criterion to evaluate the "twofold Benefit" of the renovation of buildings and their elements*. Energy and Buildings, Volume 36, Issue 1, pp 3-8, 2004

[14] Keown A.J. *Foundations of finance : the logic and practice of financial management (International ed., 6th ed. ed.)*. Upper Saddle River, N.J.: Pearson Prentice Hall, 2008.

[15] Feist W. Uberrufung der bedingten energetischen Anforderungen im Gebaudebestand bei Beibehaltung der gegenwartigen Rechtegrundlage der Warmeschutzverordnung: Studie im Auftrag des BMBar, Passivhus Instittut, Darmstadt, 1997.

[16] Feist W. Wirtschaftlichkeitsuntersuchung ausgewahlter Eergiesparmabnahmen im Gebaudebestand, Fachinformation PHI-1998/3, Passivehaous Institut Darmstadt, 1998.

[17] Krause F., Koomey J. *Unit costs of carbon savings from urban trees, rural trees, and electricty conservation: a utility cost perspective*. Applied Science Division, Lawrence Berkeley Laboatory, University of California, Berkeley, 1990.

[18] Martinaitis V., Kazakeviciusb E., and Vitkauskasb A. *A two-factor method for appraising building renovation and energy efficiency improvement projects*. Energy Policy Volume 35, pp 192-201, 2007.

[19] Galvin R. *Thermal upgrades of existing homes in Germany: the building code, subsidies, and economic efficiency*. Energy and Buildings, Volume 42, Issue 6, pp 834-844, 2010.

Appendix

Cost calculation of the LED retrofit project:

Initial Capital Cost (C)	Cost of lamps	Lamp	Qty	Lamp cost (£)	Total cost (£)
		7 watt LED GU10	8378	21.40	179,289.20
		3 watt LED GU10	2266	16.11	36,505.26
		7 watt LED AR111	1544	29.15	45,007.60
		9 watt CFL Candle	2023	3.83	7,748.09
		Total cost of lamps (£)	26,8550.15		
	Cost of installation*(£)	322,260.18			
	Total Cost (£)	590,810.33			

*According to project manager, the cost of installation, including labour cost and accessory cost roughly equals 120% of bulb cost.

Total operating cost of incumbent lamps:

Total Energy Cost	Lamp Type		240V 50W GU10	240V 35W GU10	12V 35W MR16	240V 35W AR111 spot	240V 40W Candle
	Lamp Watts		50	35	35	35	40
	Lamp Qty		8,378	1,266	1,000	1,544	2,023
	Lamp Operating Hours		6,500	6,500	6,500	6,500	6,500
	Lamp Life Time (hours per annum)		3,500	3,500	3,500	1,000	2,000
	Dimming Factor		1	1	1	1	1
	Power Factor		1	1	1	1	1
	Energy Price Variation		0.1 (2.5% annual increase*)				
	Total Energy Consumption per annum (by lamp type) (£)		272,285.00	28,801.50	22750.00	35,126.00	52,598
	Total Energy Consumption per annum (£)		411560.5				
Maintenanc-e Cost	Maintenance Capital Cost (£)	Cost of Lamps	1.12	0.90	0.59	4.95	3.83
		Cost of Accessories	negligible	negligible	negligible	negligible	negligible
	Maintenance Labour Cost (£)	Spot Relam-ping cost per lamp (£)	18.80	18.80	18.80	18.80	18.80
	Maintenance cost per lamp per annum (£)		36.99	36.59	36.01	154.38	73.55
	Total Maintenance Cost per annum per lamp type (£)		309,938.13	46,317.51	36,010.00	238,355.00	148,786.59
	Total Maintenance Cost per annum (£)		779,407.23				
Total							

Operating Cost (£)	1,190,967.73

*Annual percentage increase of fuel price is 2.5%

Operating cost of LED system:

Total Energy Cost	Lamp Type		7 watt LED GU10	3 watt LED GU10	3 watt LED GU10 (MR16)	7 watt LED AR111	9 watt CFL Candle
	Lamp Watts		7	3	3	7	9
	Lamp Qty		8378	2266		1544	2023
	Lamp Operating Hours		6500	6500	6500	6500	6500
	Lamp Lifetime (hours per annum)		40000	40000	40000	40000	10000
	Dimming Factor		1	1	1	1	1
	Power Factor		0.45	0.45	0.45	0.70	1.00
	Energy Price Variation		2.5% annual increase*				
	First Year Total Energy Consumption per lamp (kWh)		847108.889	44187		70,252.00	118,345.5
	First Year Total Energy Consumption per lamp (£)		84,710.89	4,418.70		7,025.20	11,834.55
	Total Energy Consumption per annum (£)		107,989.34				
Total Mainten-ance Cost	Maintenan-ce Capital Cost	Cost of Lamps (£)	29.15	16.11		29.15	3.83
		Spot Relamping per lamp (£)	18.80	18.80		18.80	18.80
		Maintenance cost per lamp per annum (£)	7.79	5.67		7.79	14.71
		Total Maintenance Cost per annum (£)	65,280.33	12,854.73		12,030.66	29,757.32
	Total Maintenan-ce Cost per annum	119,923.04					
Total Operati-ng Cost per annum	227,912.00						

Landscape offices at high latitude: Daylight autonomy and electric lighting savings in relation to key design features

Dubois, Marie-Claude, M Arch PhD and Du, Jiangtao, MSc PhD
Lund University, Division of Energy and Building Design, Lund, Sweden

Abstract

This paper presents a parametric study about daylight autonomy and electric lighting consumption in a typical open-plan (landscape) office space located at high latitude. The parameters studied include: furniture, climates and latitude, orientations, glazing-to-wall ratios (GWR), Venetian blind use and electric lighting control systems. The study is carried out using DAYSIM, which is based on the validated backward raytracing simulation program RADIANCE. The results indicate that the furniture can significantly reduce daylight autonomy, especially at the back of a deep room, and this parameter must therefore be considered seriously in future simulation work. Furthermore, the results show that daylight autonomy is good to excellent in Stockholm-Östersund and good in Kiruna for work stations next to the window, even on North facades. The North façade has the advantage of no direct sunlight glare compared to South. However, daylight autonomy is much more limited on the North orientation for work stations located a few meters away from the window, which suggests that deep open-plan offices with North orientation should generally be avoided. An examination of electric lighting pattern use confirmed results of earlier studies i.e. the selection of control strategy for the electric lighting system is more important than the selection of GWR and that the occupancy switch on/off system yields the highest energy use while a perfectly commissioned photoelectric dimming system can achieve very significant energy savings for all GWR, orientations and climates, compared to a manual switch at the door.

Introduction

Commercial buildings, and primarily office buildings, are classified among the building types presenting the highest energy consumption [1]. Typical primary energy intensities for offices in Northern Europe fall in the range 270-350 kWh/m^{2}yr [2]. In Scandinavia, a recent inventory [3] of energy use indicated that offices have the highest electricity use by square meter with electric lighting and fans representing the most significant portion (37.5 %) for the majority of office buildings inventoried [4]. This inventory also indicated an energy intensity of 21 kWh/m^{2}yr for electric lighting, a value which could realistically be reduced to only 10 kWh/m^{2}yr according to [5] by applying a series of technically available measures like e.g. improvements in lamp, ballast and luminaire technology, use of task/ambient lighting, improvement in maintenance and utilization factor, reduction of maintained illuminance levels and total switch-on time, use of manual dimming and switch-off occupancy sensors, and daylight utilization and harvesting, etc.

Among these measures, daylight utilisation and harvesting have the highest potential for drastically reducing electricity use of office lighting. A recent study [6] showed that using a perfectly commissioned daylight dimming system could save more than 50% of electricity use in individual perimeter office rooms located at high latitude, for any glazing-to-wall ratios larger than 20%. Furthermore, a good distribution of natural light may create a more pleasant office environment and improve the productivity and well-being of the occupants [7]. Daylit environments have been shown to increase individual productivity and human comfort, and provide the mental and visual stimulation necessary for an adequate regulation of the circadian rhythms.

When windows are wisely sized, positioned and designed, the reduction in electric lighting can also yield reduction in air conditioning and total energy use. On the other hand, over sized windows can yield higher energy use (due to higher heating and cooling loads), as shown by previous research [8] and higher occurrences of glare problems, which can in turn lead to a continuous use of shading devices. An all too common scenario in over glazed buildings is where the blinds are down to control glare and the lights are on [9]. One key design decision in low energy office buildings is thus the selection of a sufficient -yet not excessive- glazing area that allows a satisfying view out while preventing overheating, glare and wastage of cooling and heating energy.

This article analyses the daylight utilization potential in typical landscape offices located at high latitude i.e. mainly in Scandinavia. Landscape or so-called ‘open’ workstations, were first designed by the brothers Schnelles in Germany in the 1960s. They were called Bürolandschaften (office landscapes), and their purpose was to facilitate communication and to enable workers to exchange information rapidly and informally [10]. However, landscape offices present a higher challenge for building professionals since the daylight conditions vary tremendously as a function of distance to the window. Office workers sitting next to windows receive plenty of daylight and often want to close the window shades to reduce glare while workers sitting deeper in the room suffer from absence of natural light and view out. The aim of the present study is thus to analyse daylight conditions and daylight utilization potential in typical landscape offices, taking into account the distance from the window, with the aim to provide recommendations to architects and engineers regarding key design features such as optimal glazing sizes and properties, reflectance of inner surfaces, and solar shading in relation to orientation and specific climate.

This study is part of the Swedish project ‘Energy-efficient office buildings with low internal gains: simulations and design guidelines’. This project was initiated in order to develop guidelines yielding drastic peak loads and energy use reductions, for the same investment cost as for traditional office buildings.

Method

Light simulation program and simulation parameters
The study was carried out by simulation using the validated dynamic daylight simulation program DAYSIM 3.1b [11], which allowed modeling in detail an existing furnished landscape office space (the ‘Kaggen’ building) located in Malmö, Sweden. In this landscape office, daylight autonomy and electric lighting use were studied in relation to glazing-to-wall ratios (GWR), orientation, climate, and control system for electric lighting.

DAYSIM 3.1b is based on the backward raytracer RADIANCE [12]; it uses the Perez sky model combined with daylight coefficient method to efficiently calculate illuminance distributions under all sky conditions in a year. The simulation parameters for the DAYSIM calculations were set as follows: -ab 7 -ad 1500 -as 100 -ar 300 -aa 0.1-lr 6 -st 0.15 -sj 1.0 -lw 0.004 -dj 0.0 -ds 0.2 -dr 2 -dp 512. These are optimal settings in the backward raytracing calculation for a relatively complex geometry. In addition, the -dds calculation setting was used, which is a standard daylight coefficient model for ‘dynamic daylighting simulations’ (DDS). The DDS standard outperforms the original validated DAYSIM approach, notably in cases where sensors are subjected to sudden changes in solar exposure e.g. for sensors located far from the window. Generally, it allows more accurate predictions of illuminance, especially in the direct calculation and for high illuminance levels from direct sunlight [13].

Description of the office model
An existing furnished landscape office space (the ‘Kaggen’ building, see Fig. 1) located in Malmö, Sweden was used as base model for the study. One typical deep landscape office space of this building was modelled using Google SketchUp and exported to DAYSIM. This office space, which is presented in Fig. 2, had an initial ceiling height of 3.0 m in the perimeter (within a band of 3.6 m from windows) and 2.7 m in the remaining part of the space. A specific sector of this office space measuring 13.3 m deep was studied in detail in the simulations since this sector received considerably less daylight in the back of the room. The model was also fully furnished with a density, configuration and height almost identical to the real space as shown in Fig. 1-2.

Fig. 1: Interior pictures of the Kaggen building in Malmö, Sweden.

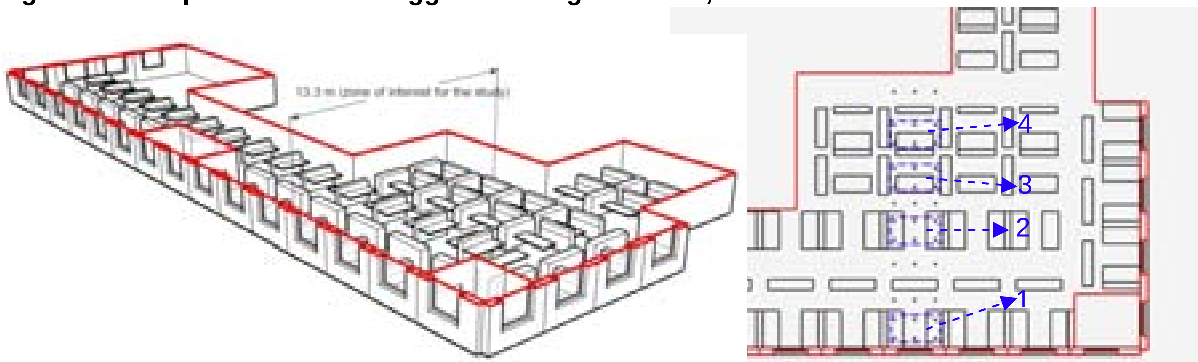


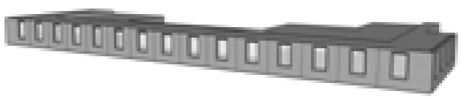
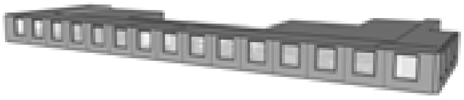
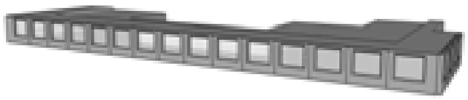
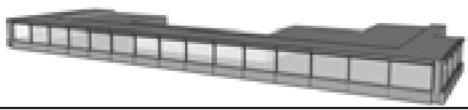
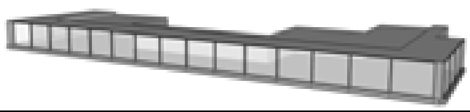
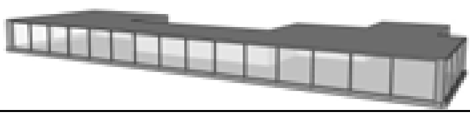
Fig. 2: SketchUp model of the office space for the case 30% glazing-to-wall ratio.

The façade of the landscape office was divided into 3m-wide and 3m-high prefabricated modules and the glazing-to-wall ratios (GWR) were defined as a function of each of these modules, corresponding to approx. 20-30-40-60-80% of the facade area facing indoors. One case was added with an exposed concrete ceiling slab and no mechanical ventilation shaft. In this case, the ceiling was at 3.4 m from the floor in the whole space. A 0.1 m-wide and 0.1 m-deep frame was built around the glazing area and centered with respect to the 0.25 m-thick outer wall. A full description of glazing size and position is presented in Table 1. The landscape office space alternately faced the South and North directions.

The reflectance of inner surfaces in the base case were 80% (ceiling), 70% (walls) and 40% (floor and furniture), which are within the ranges recommended in the European standard EN 12464-1. All surfaces were modelled as perfectly grey and diffuse.

The glazing type selected for the base case was a double pane assembly with a visual transmittance of 72%. The glazing was modelled as 'glass' material with constant RGB values (thus neutral grey colour).

Table 1: Geometrical description of the glazing areas studied

Graphical representation	Approx. GWR (%)	Exact GWR (%)	Wall section area (m^2)	W (m)	H (m)	Glazing sill height (m)
	20%	20.0	9.0	1.0	1.8	0.9
	30%	30.0	9.0	1.5	1.8	0.9
	40%	40.0	9.0	2.0	1.8	0.9
	60%	58.0	9.0	2.9	1.8	0.9
	80%	80.6	9.0	2.9	2.5	0.45
	80%h	79.6	10.2	2.9	2.8	0.45

Climate files used

The base case climate file used was Stockholm (lat. 59.65ºN, long. 17.95ºE), with data recorded at Arlanda airport downloaded from the EnergyPlus weather data website. Two other cities (Östersund, Kiruna) in Sweden were studied as well as one city in Canada (Montreal) as a reference (see Table 2). A previous study [6] has shown that it was not necessary to include the two other large Swedish cities (Malmö and Gothenburgh) as this returned almost exactly the same results as for Stockholm. The ground reflectance was set to 20% for all simulations.

Table 2: Locations, meteorological stations, solar radiation data, latitude, longitude and height of measurements. Data for Swedish cities retrieved from [14] ; and for Montreal from [15].

City	Location	Cummulated unshaded global radiation (kWh/m^2yr)	Sunshine hours[a]	Latitude	Longitude	Elev. (m)
Stockholm	Arlanda Airport	970	1821	59.65°N	17.95°E	61
Östersund	Froson	933	1536	63.10°N	14.30°E	370
Kiruna	Kiruna Airport	817	1484	67.81°N	20.33°E	452
Montreal	Intern. Airport	1351 [b]	2029	45.47°N	73.75°W	36

[a] for hours where direct radiation > 120 W/m^2.

[b] Data retrieved from the program Meteonorm.

Dimming and switching strategies for electrical lighting

Switching and dimming strategies for the electric lighting system are described in a previous publication [6].

Calculations and data analysis

A horizontal grid consisting of 36 points at desk height (0.8 m) was defined in the model for the calculation of illuminance values, as illustrated in Fig. 2 (right). The points were placed as a function of the furniture arrangement and in such way that average illuminance for 6 points could be calculated for four work stations located along the depth of this office sector (see numbering on Fig. 2, right).
The following metrics were analysed for each case:

- Continuous daylight autonomy, DAcon (%);
- Daylight autonomy max, DAmax (%);
- Electricity use for various lighting control strategies (kWh/m^2yr).

These metrics are described in previous papers [6, 11, 16]. For daylight autonomy calculations, benchmark illuminance values of 500 lx were used. Rogers [16] proposed that DAcon levels of 80% - 100% represent some excellent daylight designs, while good daylighting designs fall in the 60% - 80% DAcon range, and adequate daylighting designs fall in the 40% - 60% DAcon range. Regarding DAmax, the threshold proposed by Rogers [16] for acceptable limit of DAmax is 5%, i.e. DAmax values above 5% are not acceptable.

The calculations were performed assuming that the office was occupied Monday through Friday from 8:00 to 17:00 hours with an occupant leaving the office three times during the day (30 minutes in the morning, 1 hour at midday, and 30 minutes in the afternoon). Daylight savings time was assumed from April 1st to October 31st.

Results

Effects of furniture

Preliminary tests were carried out - for a South-oriented office space located in Stockholm - in order to verify the impact of furniture on the variables studied. The results showed that on average, the furnished room had DAcon values which were 9-34% lower than the empty room. This is a significant difference, which was taken into account in the rest of the simulations presented in this paper so all cases discussed in the next sections are for configurations including furniture as shown in Fig. 2.

Effects of climate

The second round of simulations consisted of studying the effect of four climates (Stockholm, Östersund, Kiruna, Montreal) on DAcon and DAmax. These results are presented in Fig. 3a-d for the four working stations located along the depth of the room. DAcon values appear in the upper section of the graphs while DAmax values are at the bottom.

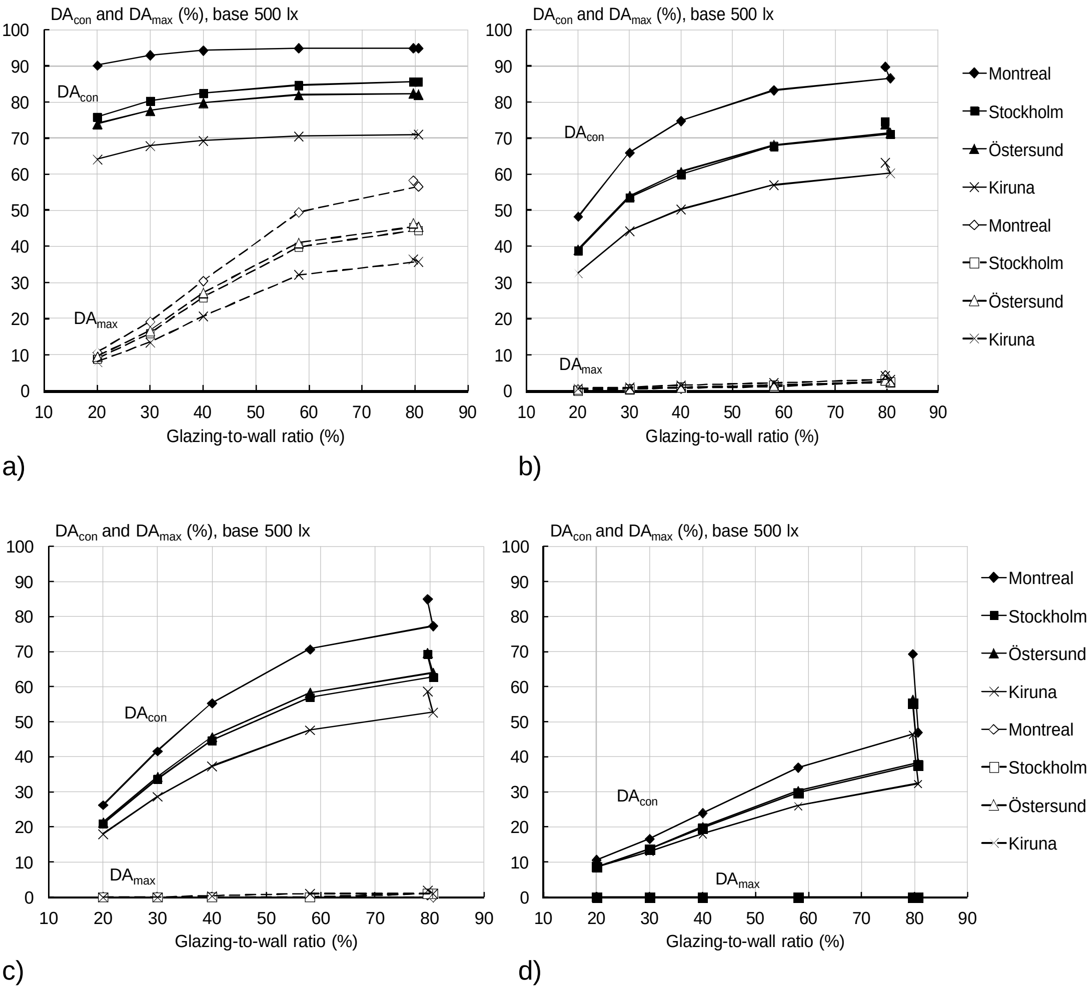


Fig. 3: DAcon (top) and DAmax (bottom) values obtained for a South-oriented office landscape located in Stockholm, Östersund, Kiruna and Montreal, at a) the first working station located next to the window (0-1.8 m from window), b) the second working station (4.8-6.6 m from window), c) the third working station (7.55-9.3 m from window) and d) the fourth working station located at the back of the room (9.6-11.3 m from window).

Fig. 3a-d show that directly next to the window (Fig. 3a), there is hardly any benefit of having large GWRs; the curves are very flat. Increasing GWR from 20 to 40% brings an increase in DAcon of about 5 points on the DAcon scale in all climates studied. Also, further increases in GWR only bring marginal additional benefits in terms of DAcon. However, the increase in DAmax (bottom of Fig. 3a) as a function of GWR is significant and linear up to GWR 60%. Therefore, for work stations located next to the window, the increase of direct sunshine and related glare problems is significant with increases in GWR, which explains the need of visual protection devices, especially for occupants sitting next to windows.

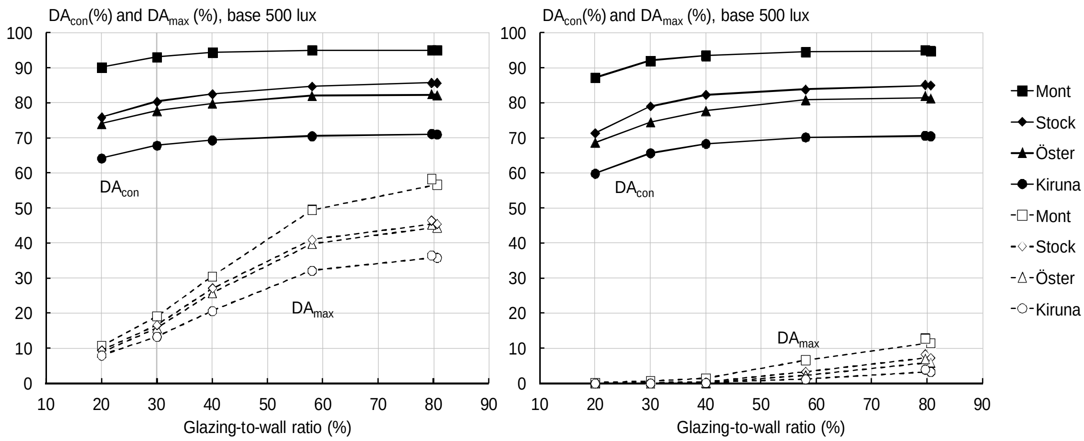
Comparing Fig. 3a with 3b-d, the further away from the window, the more straight and 'linear' the relation becomes between GWR and DAcon. This is especially obvious in Fig. 3d, where the curves are almost completely linearly dependent on GWR. Note also that in this particular figure (3d), the increase in ceiling height (in the case of GWR 80%h) and addition of glazing in the upper part of the facade does have a significant effect on DAcon. Also note that DAmax values (bottom) are negligible for work stations 2, 3 and 4, in all climates studied (Fig. 3b-d).

Fig. 3a further show that DAcon is 'excellent' (> 90%) in Montreal for all GWR, 'good to excellent' (75-85%) in Stockholm-Östersund and good (65-70%) in Kiruna for occupants sitting directly next to the window. At the second work station (Fig. 3b), DAcon is in the range ‘good’ from GWR 40% and up in Stockholm and Östersund while it is ‘good’ in Montreal for GWR 30% and up. In Kiruna, GWR of 80% is needed to obtain a ‘good’ daylight autonomy at the second sitting position.

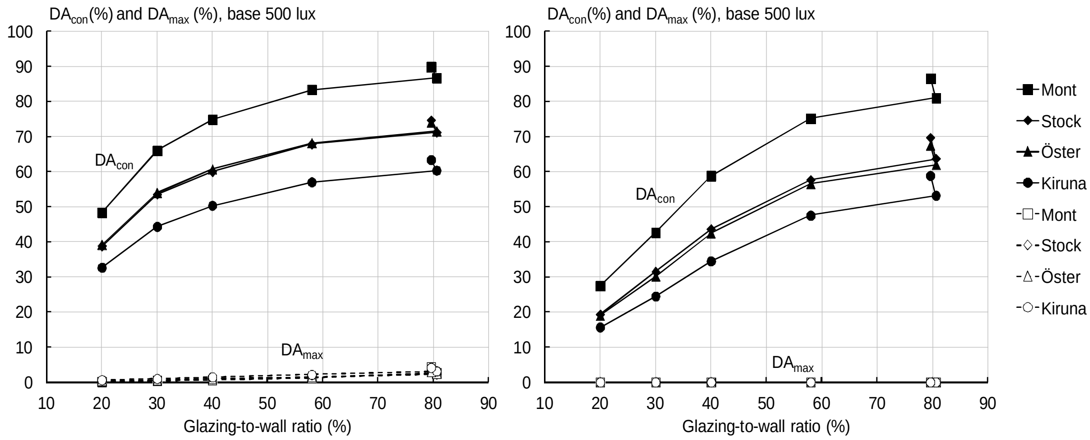
However, for occupants sitting deeper in the room (fourth work station, Fig. 3d), DAcon increases more or less linearly i.e. from 10-38% in Stockholm-Östersund and from 10-30% in Kiruna with increasing GWR (20 to 80%). In this case, daylight autonomy is much more limited and falls below the range ‘adequate daylight design’ for all GWR and climates except for the case with increased ceiling height to 3.4 m and glazing in the upper part of the façade, which ‘boosts’ DAcon by a 15-20 points on the DAcon scale.

Effects of orientation

In the next round of simulations, the effect of orientation was studied, by only comparing North and South orientations. A previous paper [6], which presented results for the four cardinal orientations, has shown that DAcon of East and West facades is almost identical and exactly between that of North and South orientations. This means that DAcon of East and West facades can more or less be deduced from the results obtained for South and North orientations, which justifies eliminating these runs in the present study. Fig. 4a-d present the results of these simulations for Montreal, Stockholm, Östersund and Kiruna for the first, second, third and fourth work station from the window.

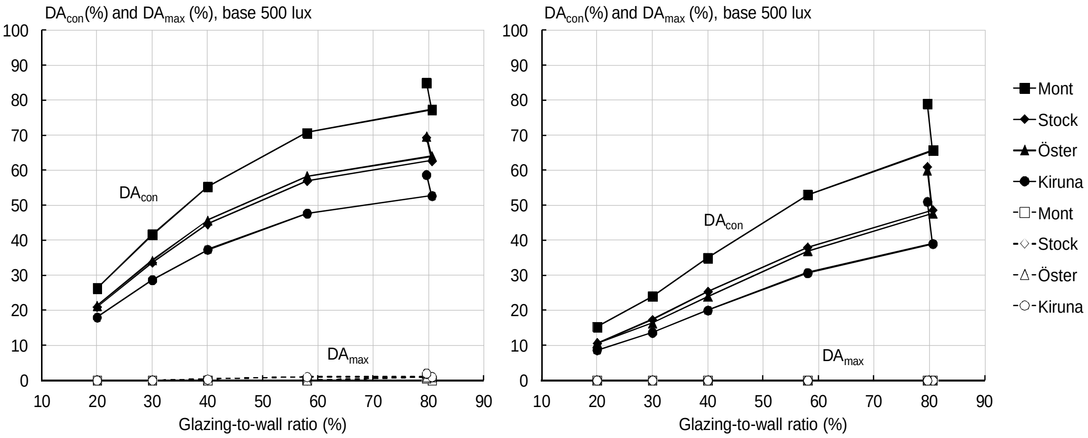


a)

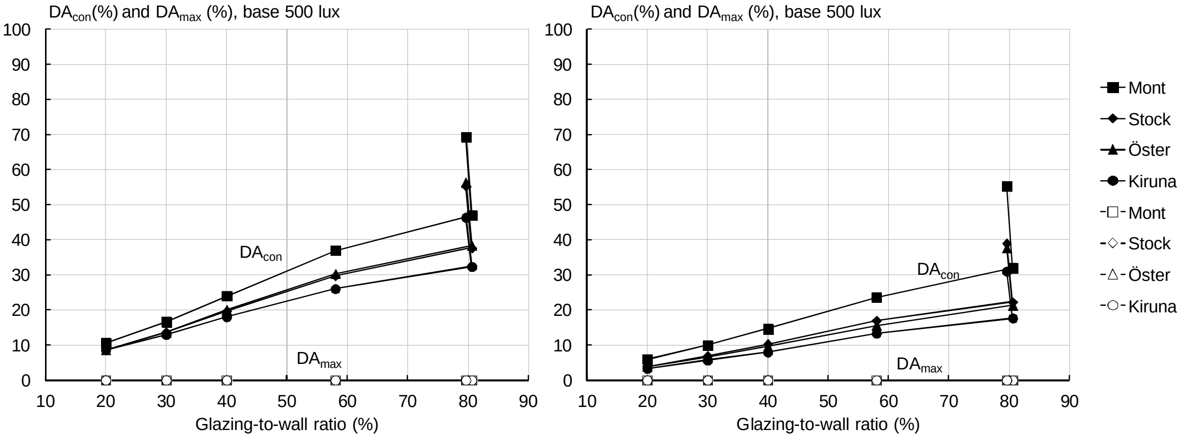


b)

Fig. 4: DAcon (top) and DAmax (bottom) values obtained for a South (left) and North (right)-oriented office landscape located in Stockholm, Kiruna and Montreal, at a) the first working station located next to the window (0-1.8 m from window), b) the second working station (4.8-6.6 m from window), c) the third working station (7.55-9.3 m from window) and d) the fourth working station located at the back of the room (9.6-11.3 m from window).



c)



d)

Fig. 4: Continued.

Fig. 4a shows that, at the first work station, orientation has a negligible impact on DAcon, for all GWR except perhaps 20% where DAcon is slightly lower on the North facade. Fig. 4a also shows that DAmax is very low on the North façade, in all climates studied but increases sharply and linearly as a function of GWR on the South façade. The conclusion from this figure is thus that the North façade is a potentially interesting façade for offices because it may offer good levels of DAcon, even for relatively small GWR (30%), without the detriments of direct sunlight glare. However, this is true only if the occupant is sitting relatively close to the window on the North façade.

Fig. 4b-c show that, for the second and third work stations, orientation has a larger impact on DAcon than climate, but only for smaller GWR. For large GWR (i.e. > 60%), the effect of climate on DAcon is more important than the effect of orientation. On the North façade, relatively large GWR ratios are needed to obtain 'adequate' DAcon (30% GWR in Montreal, 40% GWR in Stockholm and 60% GWR in Kiruna for the second work station and 45% GWR in Montreal, 60% GWR in Stockholm, 80% GWR in Kiruna for the third work station). These figures thus show that DAcon is significantly more limited with a North orientation, for the second and third work stations and large GWR are needed to reach acceptable DAcon. On the other hand, the DAmax curves are all close to zero, indicating that there is no problem of direct sunlight glare on the South or North façades for work stations located some meters away from the window.

Fig. 4d shows that, at the fourth work station, the impact of orientation is generally larger than the impact of climate, for all GWR. This figure also shows that DAcon increases more or less linearly with increasing GWR both on the North and South facades. The effect of increasing ceiling height is significant for DAcon also both on South and North facades. Finally, Fig. 4d shows that DAmax values are all zero for all GWR both on South and North facades and thus direct sunlight is not a problem at such distance from the window.

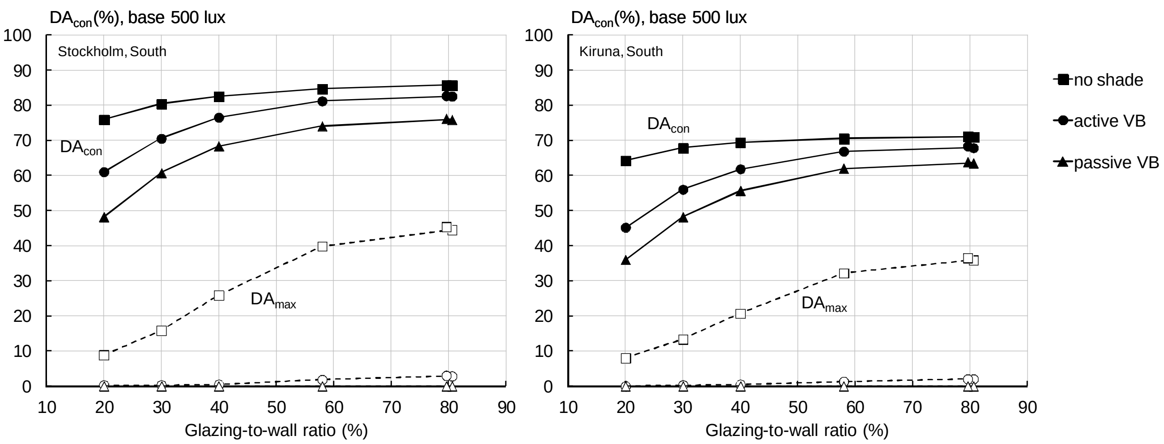
Effects of venetian blinds

According to Reinhart [17], one common source of error for overoptimistic energy savings predictions with daylight utilization is the treatment of blinds: it is often assumed that blinds are retracted all year round (maximum daylight availability). The next series of simulations thus consisted of testing a more realistic situation i.e. one with a venetian blind that the occupant could control. In these simulations, a simpler blind model was used, which is pre-programmed in DAYSIM to let 25% of daylight pass through the window.

Two simulation alternatives were studied on two orientations (South, North) in Stockholm and Kiruna:
1) An active user (called 'active VB') i.e. a user who opens the blinds in the morning, and partly closes them during the day to avoid direct sunlight. In this case, blinds are manually fully lowered as soon as outside direct solar irradiance above 50 W/m^2 hits any of the 36 points on the desk surfaces. Note that the blinds are re-opened once a day in the morning upon arrival.
2) A passive user (called 'passive VB') i.e. a user who keeps the blinds partly closed throughout the year to avoid direct sunlight. In this case, we thus assume that any incident solar radiation above 50 W/m^2 on any of the reference points on the desks (Fig. 2) will motivate an occupant to rise from his desk and close the blinds but the blinds will normally remained closed afterwards.

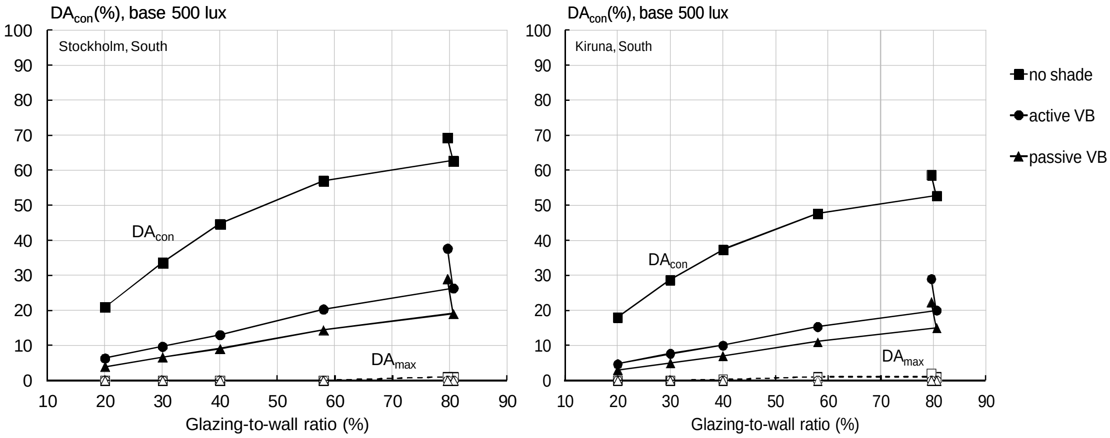
The results are presented in Fig. 5a-d for the South orientation only and for Stockholm (left) and Kiruna (right). Note that we present only the results for three sitting positions due to lack of space in this paper. The results show that the use of Venetian blind reduces DAcon quite significantly, especially for work stations located further away from the window. Also, note that the further away from the window, the smaller the difference between a passive and an active user. Close to the window, at the first sitting position (Fig. 5a), the use of a Venetian blind does not reduce DAcon very much with an active user, especially for large GWR. The reason for this is that the blind is used only when exterior daylight levels are high (exterior direct solar irradiance above 50 W/m^2). In these cases, if 25% of daylight still penetrates through the window-blind assembly, it may well be sufficient to provide a good level of daylight autonomy at this sitting position.

Furthermore, the results show that, although much lower DAcon levels are obtained with 20% GWR combined with blind than 80% GWR combined with blind, DAcon obtained for the case 80% GWR with blinds is roughly the same as for 20% GWR with no shade.

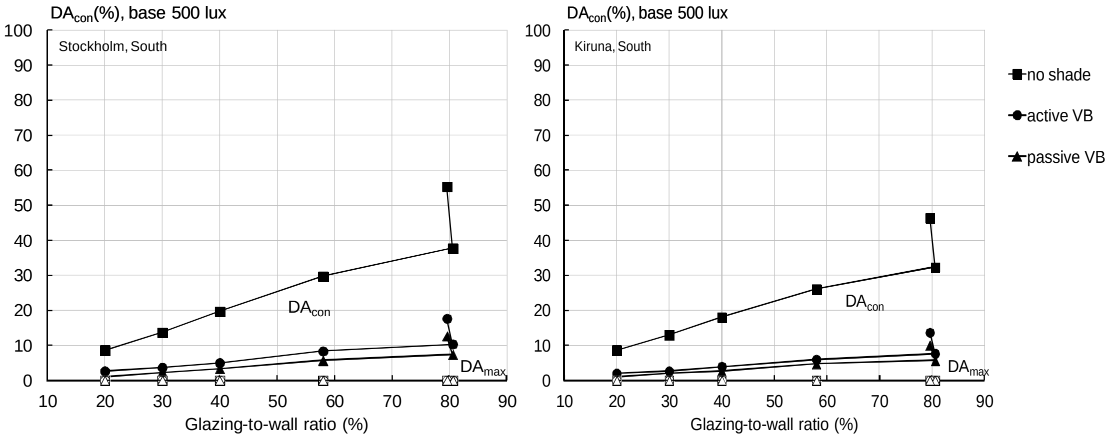


a)

Fig. 5: DAcon (top) and DAmax (bottom) values obtained for a South-oriented office landscape located in Stockholm (left) and Kiruna (right), at a) the first working station located next to the window (0-1.8 m from window), b) the third working station (7.55-9.3 m from window) and c) the fourth working station located at the back of the room (9.6-11.3 m from window).



b)



c)

Fig. 5: Continued.

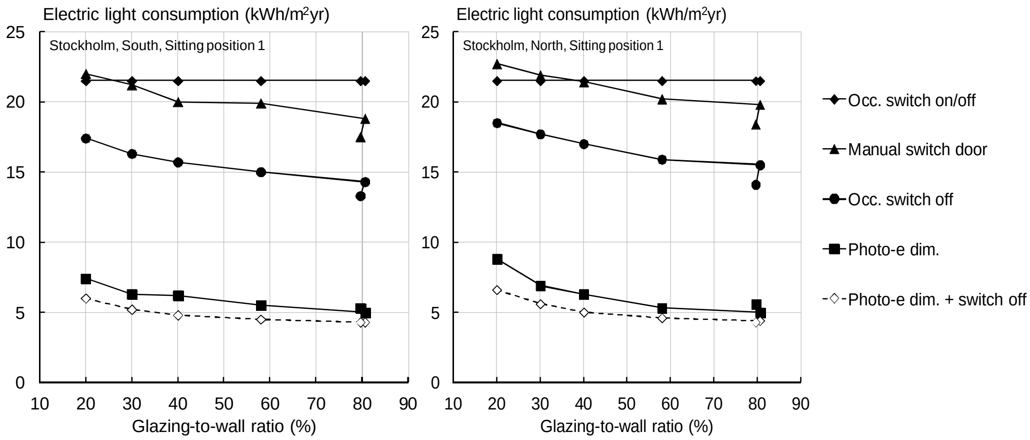
Effects of control system of electric lighting on energy use in relation to GWR and orientation

The last analysis consisted of studying the effect of GWR on electric lighting utilization as a function of control systems, in relation to orientation and climate. The results for Stockholm are presented in Fig. 6. Note that only three sitting positions (1, 3, 4) are presented due to lack of space in the paper.

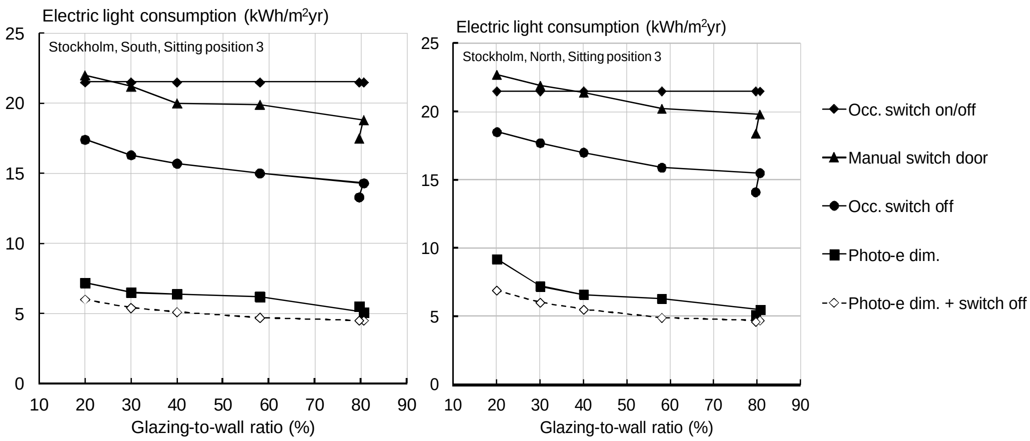
Across the whole working area, using the systems with photoelectric dimming is generally the best control strategy according to electrical energy savings. Adding an 'occupancy switch off' function provides additional energy savings. The least efficient systems are the 'occupancy switch on/off' and manual 'switch on/off', which use more energy than other systems. As shown in a previous paper [6], more electrical energy is needed for the 'occupancy switch on/off' system than the manual switch on/off system, especially for the larger GWR. This is due to the fact that the 'occupancy switch on/off system' does not take any consideration of the exterior illumination levels and only adjusts as a function of occupancy while the 'manual switch on/off' does take consideration of ambient light levels. The results also show that the variation of GWR has no effect on energy use when using the 'occupancy switch on/off' system.

For other systems, increasing GWR reduces lighting energy use, especially at the fourth sitting position (deeper in the working area). However, sitting positions (1 and 3) near the window only see a relatively modest energy drop by increasing the GWR compared to the significant effect of the selection of control system for lighting.

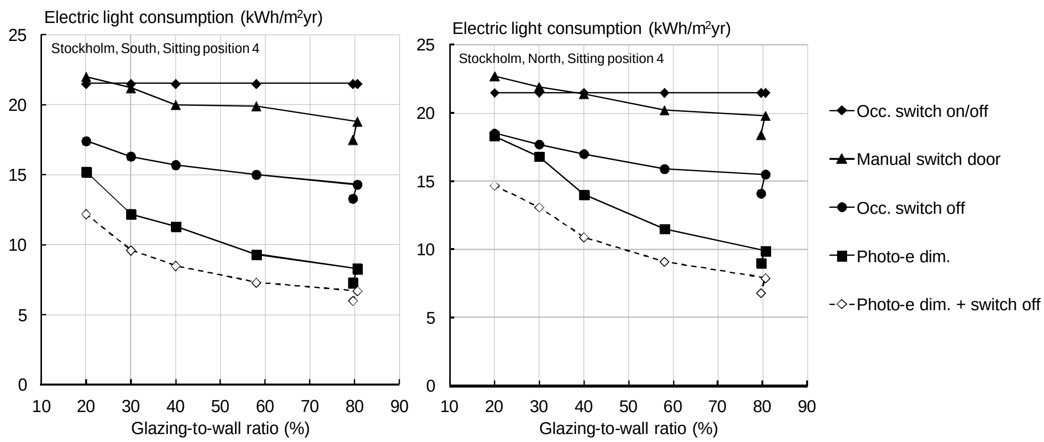
Similarly, the lighting energy use with 'occupancy switch on/off' is not influenced by orientation (compare Fig.6a and 6b). For the four other systems, the orientations (North and South) have a negligible impact on lighting energy use in the areas near window whilst the deeper area (sitting position 4) sees a relatively bigger difference. The South-facing room with the four controls uses less lighting energy than the North-facing room, which is in line with the findings about the relationship between DAcon and orientation.



a)



b)



c)

Fig. 6: Electric lighting consumption (kWh/m^{2}yr) for the South (left) and North (right) orientation in Stockholm, for the first (a), third (b), and fourth (c) sitting positions from the window.

Discussion and conclusions

This study investigated by simulation the daylight autonomy and light energy use in landscape offices with variable glazing-to-wall ratios, climates, orientations, venetian blind use and lighting control systems at high latitude areas. The discussions and findings are the follows:

Firstly, from a methodological point of view, it has been found that the impact of a realistic furniture arrangement on daylight autonomy may be significant i.e. up to about 35%. It suggests that furniture should be considered in all future simulation studies.

Secondly, an increase in ceiling height and addition of glazing in the upper part of the facade does have a significant effect on DAcon for work stations located at the back of deep rooms. Direct sunlight and related glare problems are negligible for working positions in the middle and deeper areas of offices. This suggests that it would be a good idea to locate circulation or informal meeting spaces in the periphery, and formal computer work stations a bit further away from the façade. This would be possible to keep an open view and make the window free from shading devices, which greatly reduce the daylight autonomy, as shown in this study.

Thirdly, the latitude and climate do have significant effect on daylight autonomy (e.g. an average difference of about 10 points on the DAcon scale between Montreal and Stockholm-Östersund; the same difference between Stockholm-Östersund and Kiruna). While this could mean that we should use larger GWR at high latitude, we also have to balance the thermal losses under very cold weather conditions. Furthermore, at high latitude, the sun is lower and more bound to create direct and reflected glare problems. Very large GWR increase the risk for such problems in sunny winter days.

Fourthly, the daylight autonomy is significantly more limited on the North façade, but only for work stations that are a few meters away from the window. Large GWR are needed on the North façade to reach acceptable daylight autonomy. Since these large GWR are likely to result in much larger heating loads as shown by previous research [18], the need for daylight autonomy has to be carefully weighed against the need for providing thermal comfort and heating the building at low cost. In general, we observed that the further away from the window, the more important was the effect of orientation compared to the effect of climate. This means, perhaps, that deep landscape offices should not be planned at all on North facades since daylight autonomy will be very limited for work stations located away from the window. However, for the sitting position directly next to the window, the North façade may be potentially even more interesting than the South facade because there is no direct sunlight penetration on the North orientation.

Fifthly, the use of Venetian blind reduces daylight autonomy significantly with active and passive users, especially for work stations located further away from the window. More importantly, the same daylight autonomy level is obtained for the case with smaller GWR (20%) and no blind and the case with largest GWR (80%) with blinds. This might indicate that it is preferable to have smaller glazing sizes and no blind, than very large GWR with a venetian blind which is likely to be down more often due to the presence of large direct sunlight patches. Previous experiments [19] have shown that the use of blinds correlates with the presence of direct sunlight patches. However, other research has also demonstrated that direct sunlight patches are acceptable and even desirable up to a certain limit [20] and even, that the size of sunspots does not affect significantly the perceived glare [21].

Finally, the potential for electricity savings with photoelectric daylight dimming is substantial for all areas located in the periphery of buildings. The control systems with occupancy switch on/off yield the highest electricity use, even compared with a simple manual switch near the door. At the other extreme, a perfectly commissioned photoelectric dimming system yields reductions in electricity use of more than 50% compared to a manual switch at the door, for all GWR, orientations and climates studied, for the areas closest to the window.

Acknowledgements

The authors thank Bengt Hellström (Lund Univ.) for help with climate data as well as Åke Blomsterberg (Lund Univ.), Ola Dellson (White architects, Malmö), Katarina Heikkilä (NCC Teknik, Göteborg), Thorbjörn Laike (LTH, Lund, Sweden), Peter Pertola (WSP, Stockholm), Rikard Sjöqvist (Midroc, Malmö), Hans Wetterlund (WSP Environmental, Göteborg), for useful comments during reference-group meetings. This work was supported by CERBOF (Centre for energy and resource efficient construction and management of buildings); SBUF (the development fund of the Swedish Building trade); and NCC Construction Sweden.

References

[1] Santamouris M., Argiriou A., Dascalaki E., Balaras C. & Gaglia A. *Energy characteristics and savings potential in office buildings*. Solar energy. 1994, pp. 59-66.

[2] Campbell J. *Use of passive solar energy in offices. In P. O'Sullivan (ed.), Passive solar energy in buildings.* The Watt Committee on Energy. Elsevier Applied Science Publ.1988.

[3] Statens energimyndighetenen. Energi i våra lokaler. *Resultat från Energimyndighetens STIL2-projekt. Delrapport från Energimyndighetens projekt Förbättrad energistatistik i samhället*. 2010. www.energimyndigheten.se/stil2

[4] Statens energimyndighetenen. *Förbättrad energistatistik för lokaler – "Stegvis STIL" Rapport är år 1: Inventeringar av kontor och förvaltningsbyggnader*. 2006. ISSN 1403-1892.

[5] Dubois M-C. & Blomsterberg Å. *Energy saving potential and strategies for electric lighting in future low energy office buildings: a literature review*. Energy and Buildings. 2011, pp. 2572–2582.

[6] Dubois M-C. and Flodberg K. *Daylight utilization in perimeter office rooms at high latitudes: Investigation of key design features by computer simulations.* Lighting Research and Technology. 2012, In press.

[7] CIBSE. *Energy Efficiency in Buildings (CIBSE Guide F)*. The Chartered Institution of Building Services Engineers. 2004.

[8] Poirazis H., Blomsterberg Å., Wall M. *Energy simulations for glazed office buildings in Sweden*. Energy and Buildings. 2008, pp. 1161-1170.

[9] Tzempelikos A. & Athienitis AK. *The impact of shading design and control on building cooling and lighting demand*. Solar Energy. 2007, pp. 369-382.

[10] Sunstrom ED. *Work places*. Cambridge University Press (UK). 1986.

[11] Reinhart CF. & Walkenhorst O. *Dynamic RADIANCE-based daylight simulations for a full-scale test office with outer venetian blinds*. Energy and Buildings. 2001, pp. 683-697.

[12] Ward Larson G, Shakespeare R. *Rendering with Radiance*. San Francisco: Morgan Kaufmann Publishers (USA), 1998.

[13] Bourgeois D., Reinhart CF. and Ward G. *Standard daylight coefficient model for dynamic daylighting simulations*. Building Research and Information. 2008, pp. 68-82.

[14] Swedish Meteorological and Hydrological Institute (SMHI). Normals 1961-90, available via Internet www.smhi.se, consulted on October 5, 2011.

[15] Environnement Canada. National Climate Data and Information Archive, http://climate.weatheroffice.gc.ca/Welcome_e.html, consulted on October 5, 2011.

[16] Rogers Z. *Daylight metric development using daylight autonomy calculations in the sensor placement optimization tool*. Boulder, Colorado: Architectural Energy Corporation, 2006.

[17] Reinhart CF. *Effects of interior design on the daylight availability in open plan offices*, report NRCC-45374, National Research Council of Canada, Institute for Research in Construction, Ottawa, 2002.

[18] Flodberg K., Blomsterberg Å. and Dubois M-C. *Future zero-energy office buildings with low internal heat gains: A parametric study performed with dynamic simulations*. 2012, Submitted to Energy and Buildings.

[19] Bülow-Hübe H. *Energy-Efficient Window Systems: Effects on Energy Use and Daylight in Buildings*. Thèse de doctorat. Lund: Lund University, Department of Construction and Architecture, Division of Energy and Building Design. 2001.

[20] Boubekri M., Hull R. and Boyer L. *Impact of window size and sunlight penetration on office workers' mood and satisfaction: A novel way of assessing sunlight, Environment and Behavior*. 1991, pp. 474-493.

[21] Boubekri M and Boyer LL. *Effect of window size and sunlight presence on glare*. Lighting Research and technology. 1992, pp. 69-74.

Closing the Gap between Design Goals and Measured Performance with Integrated Building Facades

Stephen Selkowitz
Windows and Daylighting Group
Lawrence Berkeley National Laboratory

Eleanor Lee
Windows and Daylighting Group
Lawrence Berkeley National Laboratory

Charlie Curcija
Windows and Daylighting Group
Lawrence Berkeley National Laboratory

Key words: facades, daylighting, integrated controls, energy performance, visual comfort

Abstract

New building energy requirements are focusing more attention on the actual operational performance of building's in-use. The challenges to achieve specific efficiency measures are captured in diverging views on glazed buildings. Poorly designed, substantially glazed facades are obviously a major performance issue for buildings, both in terms of energy performance and occupancy satisfaction. But even when the façade and building envelope are "properly designed" the building takes risks since the envelope design needs to be fully integrated with a whole building systems design.

The building envelope is subject to a wide range of temperature and solar extremes. No fixed glazing solution by itself can be guaranteed to perform across all climate extremes. . A high performance building facade requires the integration of glass with framing, provisions for controlling air leakage and providing ventilation, managing solar gain in summer vs winter, and admitting daylight to offset electric lighting, while controlling glare. And it must operate under a wide range of highly variable conditions- night to day, summer to winter, north to south. The technical potentials are diverse, promising, and growing. But the options that are affordable, reliable, and workable still lag behind what is possible.

This paper addresses the gap between idealized performance goals and measured reality. It explores sample results from simulation studies using new tools that define performance boundaries of how integrated facades "could" perform, and then comparing these performance expectations with a limited set of measured data on how the systems perform in practice.. As part of several DOE and GSA programs we are monitoring a number of potentially high performance façade systems and using the collected performance data to guide both further development and refinement of the systems and to improve the tools we are producing for architects and engineers. The gap exposed in these feedback loops between design expectations from the tools and measured data from the field can then be used to guide further recommendations about improving installation and commissioning, and operating requirements to ensure better overall performance in terms of energy efficiency and comfort.

Introduction and Background

Building energy use in the United States exceeds 40 Quads/year (42 exajoules/yr) and constitutes the single largest end use of energy in the United States. Buildings are responsible for about 40% of carbon emissions, consuming over 70% of all electricity [1]. Windows are responsible for about 10% of total building energy use or about 4-5% of total US energy consumption. [1] Windows do not directly consume energy but impact energy use indirectly in several pathways. They lose heat in winter thus increasing heating demand, and in summer they add solar gain thus increasing cooling energy use. In addition, they have the potential to offset about 1% of additional total energy use if they can provide useful daylight that allows electric lighting to be dimmed or turned off. [2]

In this paper we focus on the fenestration in commercial buildings although the underlying issues apply to virtually all buildings. “Fenestration” includes glazing, framing, shading and ancillary devices that are part of the complete window system.

There is no single action that can dramatically reduce the energy use attributable to windows. Building designs and operation reflect the interaction of many issues and trends including not only the technical constraints of available technologies but also key societal, economic and cultural trends.. Glazing and fenestration are key elements of the building envelope that are part of the architectural expression of the building and also provide occupants with a visual connection with the outside world, providing daylight to enhance the quality of the interior work environment. The building skin must operate dynamically, serving a critical function to help maintain relatively stable interior working environments with highly variable weather conditions outdoors.

The primary technical challenges of environmental control include heating, cooling and lighting which directly affect the overall building in terms of yearly energy costs and the associated carbon emissions which makes a global contribution to climate change and global warming. In the aftermath of the 1970’s energy crisis, a leaky single glazed window was suddenly a problem worth remedying. 40 years later most windows are improved thermally but the highly glazed, transparent building façade has become one of the iconic images for “green buildings”, placing new demands on designers and manufacturers. We believe there is both great opportunity to reframe the role of the façade in buildings but also great risk that the potentials will not be captured as practical savings in the real world.. The new challenge is to provide a fully functional façade with integrated lighting systems that operate appropriately under a wide range of environmental conditions to support and enhance the comfort and productivity of building users. . These rigorous performance goals must be achieved in practice, not theory, so the design solutions must be affordable and then must operate over long periods with minimal maintenance if they are to be accepted and purchased by building owners.

It has become clear that the overall performance of buildings does not reliably meet design expectations. The reasons involve varied aspects of design, construction, commissioning, occupant use, facility operation and maintenance. This level of uncertainty and risk, both real and perceived, is now beginning to be reduced by new mandatory and voluntary requirements to collect and disclose actual performance in-use building data. Extensive computer simulation to analyze and optimize the designs of high performance facades will continue to be useful, particularly if they are utilized to better understand the range of expected and uncertain performance outcomes.. But simulation must also be complemented by measured performance data so that dynamic, high performance building façades can demonstrate that expected energy impacts are achieved.

Establishing Fenestration Performance Requirements in Buildings

There are two divergent views of the role of glazing, and in particular the use of highly glazed facades, in energy efficient buildings. The two opposite positions are considered below,:

1. “Highly Glazed Facades increase Energy Use in Buildings” – most glazing has poor thermal performance relative to insulated walls and even worse summer impacts for cooling energy and peak cooling loads; furthermore highly transparent, facades create severe glare that results in the use of internal shading using blinds thus limiting the ability to reduce artificial lighting and energy use. Dimmable lighting controls and operable shading can both help to reduce energy but are currently too expensive and complex to be used effectively. So glazing should be kept to minimum areas mandated by building standards, with fixed, non-mechanical solutions such as overhangs wherever possible to minimize overheating and glare.

2. “Glass is a Key Component in an energy efficient building” – people like to connect with the outdoors thereby improving well-being and satisfaction. In addition, enhancing daylight savings during occupancy hours will require pushing daylight deeper into occupied spaces. This requires moderate to large glazed facades of reasonably high transmission, e.g. > 40%. Good façade design manages glare and contrast by separating the glazing into “view elements” and “daylight elements”, each with appropriate glazing and dynamic shading. These designs can then offset 60-80% of lighting energy use in the outer 5 meters and a further 30-60% in the deeper spaces. Furthermore, the thermal loads for heating in colder months can be minimized by improving insulation (lower U values), and with the ability to collect and redistribute solar gain The overall cooling energy use and peak cooling can be managed through a combination of non-mechanical spectrally selective glazing, and with dynamic solar control via smart glass or mechanically operable shading systems.

These two perspectives can be presented as; 1) “standard practice today with routine design” and 2) “best practice with aggressive performance goals and enhanced budgets”. The challenge for enhanced energy efficiency is to determine how achievable this second goal really is – in terms of energy efficiency and improved building services, and whether it is scalable and capable of becoming common practice..

Performance Potentials: Components, Systems, Buildings and Building Stock

Performance goals for fenestration systems in the U.S. can be defined in in terms of “performance” and “prescriptive” approaches. This also extends to the different levels in terms of the individual glazing units to the performance of the façade system to the overall building energy performance.

Expectations for energy use will differ depending on the nature of the building stock, the climate and which metrics are used. For existing older buildings, often with single glazed, punched windows, heating loads are excessive. For newer buildings with thermally improved glazing but with larger window areas and increased solar gain cooling is the greatest challenge. Climate obviously is a driver- much of the construction in the last decade in the U.S. was in Florida, Texas, Arizona and other sun-belt states with much higher cooling loads.

Inefficiencies in power plants and the grid typically means that energy use measured at the point of demand (on site) gives a different view compared to energy measured at the power plant. The latter typically triples the impact of a kilowatt-hour of energy used for lighting, fans and cooling, compared with a on-site gas heating. Increasingly carbon is a metric of environmental interest and there is a range of almost ten to one in the ratio of kilograms of carbon per kilowatt hour of electricity when comparing electricity from coal fired power plants vs hydro and nuclear plants. [1]

Comparisons have been made between the national energy consumption of the current stock of windows in US commercial buildings with hypothetical scenarios where all the glazing is replaced with improved products in Figure 1. The current stock consumes about 1.4Quads of energy with about two-thirds heating and one-third cooling.[1] Replacing that stock with the mix of windows sold today that meet current building codes, would reduce the energy use modestly. Converting all windows to spectrally selective low-E equivalents makes a more dramatic reduction of about 0.85Quad by reducing both heating and cooling.

Dynamic window systems whose solar optical properties (both window/shading system) can be dynamically controlled over a wide range, can virtually eliminate the cooling impacts and provide modest reductions in heating. Switching to highly insulated windows provides an additional 1 Quad of savings and shifts the windows to net positive energy flow (on average)- that is, the winter heat loss and summer gain are more than offset by the useful solar gain that offsets other building thermal losses. The final row shows the impact of using an “integrated Façade”- this adds daylighting strategies- dimming the electric lights when daylight is available- and provides an additional 1 Quad of lighting energy savings based on assumptions about the fraction of commercial floor space that is near windows or skylights. Note that the daylighting savings could be added to any of the other strategies listed above in the figure to convert them to lower energy solutions in addition to “net zero” solutions.

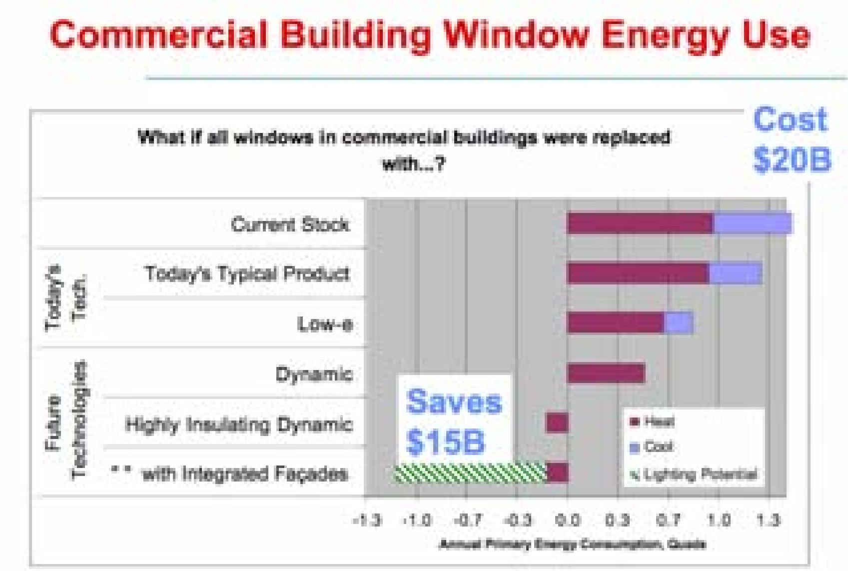


Figure 1. Potential savings from complete conversion of fenestration in US commercial building stock to the technologies indicated. (Ref. 3)

These results are intended to give a sense of the scale of national energy savings if the country launched a program to tighten existing codes and standards for new construction and aggressively sought to retrofit the entire building stock. While a detailed discussion of the policy strategies and financing options is beyond the scope of this paper, we outline below the technical requirements and opportunities to capture much of these savings as outlined in Figure 1.

Heating Energy Control: Thermal losses through the façade in winter can be addressed by specifying highly insulating glazings and frames. The façade industry today provides a wide range of solutions that reduce heat transfer below 2.0 W/m^2-C and more limited technology options that can further reduce losses to 1.0 W/m^2-C. With large glazing areas in northern climates a thermal performance in the range of .6 – 1.0 W/m^2-C may be desired. These are achieved by selecting proper glazing system with coatings and gas fills, proper framing system and a proper “window covering” to provide additional insulating value. Most of these solutions involve use of “fixed” technologies, i.e. Low E-coatings. These levels of performance are needed not only as an energy saving strategy but to minimize thermal discomfort and condensation. Highly insulating facades can greatly simplify the design and layout of HVAC systems, minimizing or even eliminating perimeter heating.

Solar Gain, Daylight and Glare Control: The emerging challenge, particularly for highly glazed facades, is dynamic control of sunlight to regulate solar gain, daylight, view and glare. The factors that determine daylight performance relate specifically to climate and building orientation specifics. These include 1) the mechanism(s) to physically control intensity e.g. absorption, reflection, 2) strategies to separate solar heat gain from daylight admittance and potentially to redirect light, and 3) the controls infrastructure by which the dynamic façade states are triggered and activated, and by which the lighting responds.

To better understand the potential for both heat loss and heat gain Figure 2 illustrates how simulation results show the net annual energy balance between heat losses, solar heat gain and daylight admission for windows in Chicago. Each of the two figures shows the total annual building energy use as a function of window area, and five different shading strategies (No shades, Interior shades, Overhang, Overhang and fins, and adjacent obstructions). It should be noted however that window area is given as a function of “floor-to-floor” spacing rather then “floor-to-ceiling”; thus 60% floor-to-floor may represent about 90% floor-to-ceiling glass. As window area is increased, thermal losses and cooling energy use due to solar heat gains increase linearly. But they are partially offset by the use of dimmable lighting controls that reduce lighting energy use.

For the cold Chicago climate we compare window “B”, a conventional double glazed window, with window “H”, a highly insulated window with 1/3 the thermal loss as window B and about 1/3 the solar gain. For the thermally poor window “B”, the daylighting benefits are maximized at 15% area and thereafter overall performance diminishes as the thermal costs of the poor window quickly equal and surpass the daylight benefits. When glazing area represents between 30-45%, the perimeter zone is “saturated” with daylight, and artifical lighting is reduced. Exceeding this range however results in increased energy use due to increased cooling requirements as a result of increasedsolar gain and thermal losses.

The simulated results clearly show that there are multiple pathways to achieving many specific targeted energy use levels. The goal of low energy use, assuming relatively poor solar-optical properties, can be achieved by a small window (e.g., point “A” at 15% for window B). However if more daylight savings, or deeper daylight penetration and view are desired, these can be achieved with more glass area. Even lower energy use can be achieved with a moderate to large-area window if advanced solar-optical and thermal properties are exploited along with exterior shading (window “H” in the Figure). These general trends are applicable throughout many climates although the specific performance details will vary.

Additional improvements in energy and peak load performance are achievable if we consider “smart” facades whose properties can change dynamically over time. These introduce more operational complexity and more challenges to actually achieve the expected performance but they are very important since we must consider thermal and visual comfort in conjunction with occupancy feedback. These are explored in more detail in the next section.

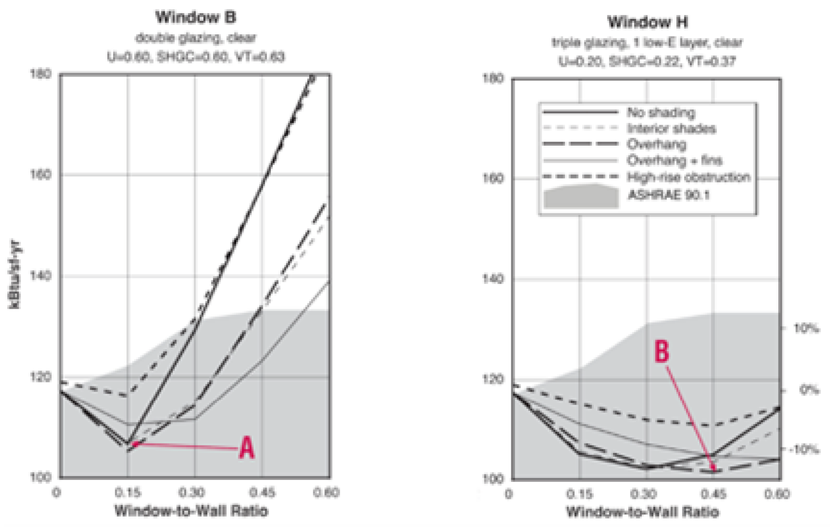


Figure 2. Annual source energy use (kBtu/ft^2-floor-yr) as a function of increased window-to-wall ratio or window area for a south-facing perimeter office in Chicago with dimmable daylighting controls and a conventional variable-air-volume (VAV) system.

- The upper edge of the grey zone indicates the maximum energy allowance prescribed by ASHRAE 90.1-2004. [Carmody et al. 2004]

Can Advanced Façade Systems with Dynamic Glazing or Automated Shading be made to Perform Reliably?

Simulations suggest that improved energy performance can be obtained by shifting to more sophisticated "dynamically controlled" systems in integrated facades. We recognize that the experience to date with many of these systems has been somewhat problematic but upon further investigation we believe many of the real problems uncovered can be "fixed". The comfort and performance of every automobile on the road today is entirely dependent on a well engineered, well tested integrated control system that simultaneously optimizes vehicle performance under all operating conditions with a range of operator selected input. The systems are durable and include on-board diagnostics to facilitate repair and replacement when needed. This provides a model of what we might expect from our building facades, recognizing that the industrial infrastructure, the sales and service channels, the business models, the ownership models, etc are all very different between buildings and cars.

While static non-mechancial solutions have their place in many building designs, given the variability of human needs and climate specifics flexible, responsive façade systems would seem to be a desirable goal. We have undertaken a series of simulation studies and limited field tests to evaluate how occupied buildings respond depending to changing conditions. This experience reinforces the challenges noted above but also reminds us that these systems can yield significant energy and peak demand reductions compared to conventionally designed systems.

Integrated "whole-building" control systems require inputs from interior and exterior sensors, the occupant(s), the utility pricing signal, and need data from operating schedules, set-points. Smart control algorithms can then adjust the various components and achieve optimal energy-efficiency, comfort, and environmental quality. The conceptual diagram for such a system is shown in Figure 3 with key system elements.

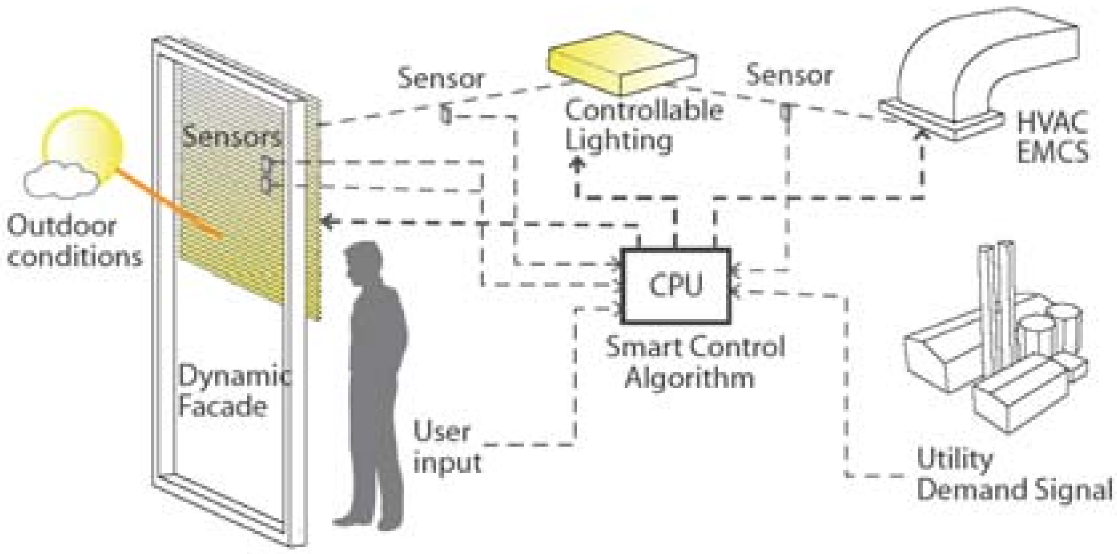


Figure 3. Diagram of an integrated whole-building control system

The ability of the façade to manage solar gain, heat loss and daylight is the fundamental to improving performance. There are a number of existing and new options that are being explored along two parallel pathways. In one case we consider the use of "smart glazings" with an emphasis on electrochromic and thermochromic glazings. The required change in solar control properties occurs in the glazing element itself. These are just becoming commercially available in sizes and at costs that allow their commercial use in buildings. In the second case we look to automated motorized shades and blinds to provide dynamic control of solar gain and glare. This class of products has been widely available for decades in Europe but are not commonly used in the U.S.

In both scenarios integrated daylight dimming controls are essential and in both cases, control strategies that address occupant needs for comfort and performance need to find a balance between occupancy needs and operation costs. While extensive parametric computer simulation of façade and building performance have been completed, computer modeling alone is insufficient to understand and support how best to integrate the full range of building services using a single BMS system. It is therefore imperative that further research combines both the optimization of engineering through field tests with the feedback from occupants in real life case-study buildings.

1. Smart Glazing Systems: Electrochromic and Thermochromic glazings

Electrochromic glazings and other types of smart glass have been under development for over 20 years. In 2012 we expect two firms to complete new production factories that will be capable of producing larger coated glazings with better quality and at lower cost. These electrochromic glazings have excellent dynamic switching range e.g. they switch reversibly from a Tv = .03 to Tv = .60; and similarly between SHGC = .1 - .40), and exhibit good durability. To extract maximum performance from such glazings requires that they be fully integrated with other building systems as shown in Figure 3. To explore these integration and operational issues we extensively tested electrochromic glazings, first in two side-by-side rooms in an existing office building in Oakland and later in a testbed building at LBNL with 3 side-by-side identical test rooms and now in operating buildings. (Fig 4) These results have been reported in past papers and on a web site: http://windows.lbl.gov/comm_perf/electrochromic .

The glazing systems are capable of meeting the range of expected modulation in SHGC and visible transmittance but controls integration remains a challenge. An ideal smart glazing would have the ability to switch to any transmittance state. The traditional “on-off” function of electrochromics is now being expanded to include intermediate switching states. The glazing can also be used as part of smarter architectural design, for example by splitting the façade into a view window and a daylight window and controlling each independently as shown in Fig 4 in a demonstration project. Other demonstrations in occupied buildings have shown again that the controls integration problem is not easily accomplished and will require more development from both a technical as well as business process perspective.

Thermochromic glazings are also now reaching the market for early demonstrations – they switch based on local temperature of the glazing which means they lack some of the flexibility of actively controlled systems but are potentially simpler to install, commission and operate. Because of their temperature dependence the details of how they are integrated into the window system become important. Depending upon those details the active layer can be more or less dependent on air temperature vs solar gain. This means that on a cold sunny winter morning the layer may not switch whereas on a warm summer morning it would. Perhaps that manages thermal properties as desired but initial field experience suggests that it will not properly address glare control. More market experience, and carefully monitored demonstrations will be needed with both passive and active systems to optimize the best fits between technologies and applications in order to resolve any bugs in the system.. Given the wide range of performance needs in buildings, we expect that the market will easily accommodate a number of types of “smart glass”.

Figure 4. Photo sequence of conference room with electrochromic glass; with independently controlled lower view windows and upper daylight windows.

2. Commercially Available Solutions: Automated Blinds and Shades

Interior shades and blinds are commonly used in most U.S. buildings today but unlike European markets, virtually none are automated or motorized and few are externally mounted. Building designers assume that these manually operated shading systems are available for occupants to control, primarily for glare, but they are not relied on to control cooling loads or overall building performance. Most energy standards do not provide credits for systems that rely on occupant action since the response is unknown and uncertain. Furthermore engineers will generally size HVAC systems assuming worst case operating procedures – e.g. that the systems are not operated as planned. This means that the economic case for conventional blinds and shades as an energy savings strategy is often hard to make although they are commonly installed because they are needed for glare control.

In addition, most models of shades and blinds make simplifying assumptions about their thermal and optical performance. Many new systems have been designed and optimized with new performance features that are not accommodated in the simulation models. We have accelerated our efforts to optically and thermally characterize virtually any type of light redirecting or controlling system and most of that new capability will soon be embedded in existing downloadable software packages. (http://windows.lbl.gov/software)

As the industry moves towards claims of larger energy savings, peak load control and eventually toward Net Zero Energy buildings we will demand much better performance from these shading systems, starting in design optimization but finishing with installed, commissioned systems that deliver on their performance promises. The same integration issues and the same controls logic outlined above for electrochromic windows apply to automated shading systems. We are currently exploring how best to adapt and adopt these systems into more routine use in buildings as an energy savings strategy, with simulation studies, outdoor test-bed experiments and building demonstrations.

Figure 5. Photo sequence of interior and exterior automated shade systems undergoing tests at LBNL's façade test facility.

Physical testing in these test bed facilities teaches us a lot about performance that is missed in the simulation world, particularly for systems involving sensor and controls. We can partially bridge that world by integrating physical testing with advanced simulation using a "virtual controls testbed". This software platform allows physical testing in our facilities to be linked real time to a series of simulation tools that allows advanced algorithms to be tested in conjunction with field measurements in the facility. The approach (see http://simulationgroup.lbl.gov/bcvtb) has been successfully used by building systems developers to support, test and optimize advanced blind and lighting controls that address minimizing energy use as well as occupant comfort.

There is also a large gap between deploying technologies in a 100 square meter test unit and then in a 100,000 square meter building. We partnered with the owners of the New York Times, their design team and several manufacturers on the development of an automated, motorized shading system with dimmable photocell- based lighting controls for use in conjunction with a high transmittance, all glass façade for their new headquarters building in New York City. The 51-story 140,000 m^2 building utilizes fixed exterior shading and fritted glass (glass with a fired ceramic pattern that blocks and diffuses some light) in some locations but the owner felt it required automated shades for sun control and glare control and for thermal and visual comfort as well as energy management. Extensive studies were carried out over 18 months in a full scale 450 sq.meter mockup of a corner of one floors. The performance of different shading and dimmable lighting systems was accurately measured and compared, and extensive performance specifications were developed from the field test program. The specifications required a fully dimmable and addressable lighting control systems and a motorized shade with sensors at each bank of windows so that shades would be responsive to local glare conditions as viewed by occupants in their workstations. This resulted in new products being developed to meet these specifications and further testing of these final products in the mockup. Special mobile commissioning carts were developed to assist the owner in verifying that the automated shading and lighting were operating properly after installation.

The building was occupied in 2007. A comprehensive energy measurement study and post occupancy evaluation is now underway and initial results seem to indicate that the systems are working well from the occupants perspective and are saving energy. More extensive information on the design and testbed can be found at http://windows.lbl.gov/comm_perf/newyorktimes.htm The findings from the new post occupancy study will be published at a future date when completed.

It should be noted that the design and implementation process that involved the full scale mock-up and extensive engagement from the LBNL research was neither typical nor scalable to all buildings. However the expectation is that key lessons learned can be adopted by suppliers, owners and designers to become part of more routine practice.

Tools and Data for Optimizing “Smart Facades” for Energy and Comfort

The initial success of the New York Times project and the extensive industry interest in utilizing similar solutions made it clear that the “technology solution sets” to easily and reliably optimize, specify and deploy these systems was not available to architects and engineers. We have therefore been working to fill this gap by evaluating off-the-shelf solutions and “emerging technologies” such as dynamic façade systems. The work include simulations, conducting field studies to better understand occupant response, and assessing energy impacts..

One of the key design objectives has been to reduce glare while allowing natural daylight to enter. Managed properly, this can help reduce electricity for artificial lighting and minimize cooling loads. We conducted a series of tests in our façade test facility to explore the performance of various shades and blinds that adjust to changing outdoor conditions and indoor needs. New techniques such as time lapse photos using high dynamic range imaging were developed and used for this test program. Similar techniques have also been used in occupied buildings to help assess occupant response to the interior lighting and daylighting conditions.

Figure 6. Exterior shading systems are being evaluated in this field testing.

- Left photo: Left chamber: a simple, single-zone, motorized Venetian blind that provides slat angle adjustments and raise-lower function. Middle chamber, a static three-zone blind is being tested where the upper, middle, and lower upside-down “V” shaped slats are ganged but positioned at different angles to block sunlight, admit daylight, and preserve view out. Right chamber: a low-e, spectrally-selective window with an interior shade as the reference case. (Ref 6)
- Right photo: Time lapse image of Interior view of motorized blind using high dynamic range photograph to assess glare conditions and visibility of task on the PC.

Suitable performance data and tools to understand and manipulate the data must be available to the architectural/engineering community. We have developed a new optics lab to measure the properties of each shading system layer, and an extension to the WINDOWS program to allow the properties of shading systems to be added to the underlying window system. This allows all the relevant heat transfer and solar optical properties to be determined. We have also developed a simulation tool for architects and engineers, COMFEN, which is based on EnergyPlus, incorporates RADIANCE and WINDOW, and can be used in early design to either assess the performance of design alternatives or to develop optimization strategies. Collectively this suite of tools should begin to provide new options for architects and engineers in the design phase of these projects.

We are also developing partnerships with 25 architecture, engineering and construction firms to share best practice across the building life cycle to address the issues raised here and observed in the field. Failures of complex façade systems, or non-optimal operation, have different origins and causes and our goal is to understand and address these. Some of these will be fixed with the development of better tools and data but many are related to details of the design, construction, and operations part of the building life cycle that we hope to address with these partnerships.

The projects will also involve selecting and examining completed buildings for lessons learned and then discovering root causes for performance problems and creating solutions to eliminate them or improve them. In parallel with these tasks we will continue to work with the technology suppliers and systems developers to ensure that the hardware and software that underlies each system is improved, and work more broadly with all the players in the building markets to bring overall costs down. We are confident that a continuous and concerted effort over a 5-10 year time frame can fundamentally improve the measured field performance of these integrated façade systems.

Conclusions

More recently, interest has grown rapidly in the U.S. to improve energy efficiency for both new and existing buildings, and to support a future goal of Net Zero Energy Buildings. Integrated façade systems can provide a key performance contribution to these ambitious goals. However, it will be necessary to make sure the design of windows/glazing/shading are properly modeled and developed in conjunction with an integrated system that links envelope, HVAC, lighting and utility services. Moreover, the façade systems need to be highly insulating and responsive to changing solar and daylight variables. These features are particularly important when the design utilizes a highly glazed façade to provide connection with the outdoors and to enhance natural daylight both for occupants well-being as well to minimize the need for artificial lighting

Moreover, while simulation results suggest there is significant potential to improve the status quo, most field studies to date have identified serious gaps in the industry's ability to deliver persistent improved energy performance. The challenge to "get this right" is a difficult one that involves many stakeholders. In addition, necessary interventions require suppliers, owners, designers, contractors, etc to all work as an integrated "team" or "partnership".

Experience from other industries suggests that high performance engineering systems can be made to work reliably but transferring and adapting those models to the building industry is the critical challenge. There are several new technology systems that we have tested that appear to have provided useful solutions that can be further developed, improved and replicated. New tools will enable architects and engineers to more reliably develop solutions that will deliver the desired performance. More demand from building owners and designers ought to stimulate manufacturers to develop improved products and integrated systems that can meet these emerging needs with lower risk and lower cost. It will take better and cheaper hardware, additional exploration of systems integration solutions, new sensors and controls, improved commissioning, a better understanding of occupant needs and preferences, and better real time, adaptive controls to fully realize the potentials of these emerging technologies and allow the design community to reliably and cost effectively reach their ambitious energy performance goals.

References

[1] _2011 Buildings Energy Data Book_, U.S. Department of Energy, 2012, download from http://buildingsdatabook.eren.doe.gov/

[2] Arasteh, D, S. Selkowitz, J. Apte, M. LaFrance, 2006, _Zero Energy Windows_, Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings, ACEEE. LBNL-60049

[3] Carmody, J., S. Selkowitz, E.S. Lee, D. Arasteh, T. Wilmert. 2004. _Window Systems for High Performance Commercial Buildings._ New York: W.W. Norton and Company, Inc.

[4] Lee, E.S., D.L. DiBartolomeo, J.H. Klems, Ph.D., R.D. Clear, Ph.D., K. Konis, M. Yazdanian, B.C. Park. 2009. *Field Measurements of Innovative Interior Shading Systems for Commercial Buildings.* ASHRAE 2009 Annual Meeting, Louisville, KY, June 20-24, 2009 and published in the ASHRAE Transactions.

[5] E.S. Lee, S. Selkowitz, D. DiBartolomeo, J. Klems, R. Clear, K. Konis, R. Hitchcock, M. Yazdanian, R. Mitchell, M. Konstantoglou; 2009, *High Performance Building Facade Solutions: PIER Final Project Report;* LBNL Report 4583E

[6] Konis, K., E.S.Lee, R. D. Clear, *Visual Comfort Analysis of Innovative Interior and Exterior Shading Systems for Commercial Buildings Using High Resolution Luminance Images*; Leukos, Journal of the Illuminating Engineering Society of North America, 9(3): 167-188

[7] A complete list of references, design guides, R&D results and tools can be downloaded from project websites:

http://windows.lbl.gov/resources/LBNLresources.pdf

http://windows.lbl.gov/comm_perf/electrochromic
http://windows.lbl.gov/comm_perf/newyorktimes.htm
http://lowenergyfacades.lbl.gov
http://windows.lbl.gov

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Systems of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098, by the California Energy Commission, Public Interest Energy Research Program, and by the New York State Energy Research and Development Authority. We acknowledge the active support of numerous LBNL colleagues on the teams that carried out the projects described here, our partners at the New York Times, and numerous other public and private firms that worked with us in these projects. A detailed listing of project partners can be found on the websites.

Renovation of “Earth Port” for Net-Zero Energy Building

Takehito IMANARI, Satoshi OGAWA, Tokyo Gas Co., Ltd.

Shin-ichi TANABE, Waseda University

Tatsuo NOBE, Kogakuin University

Masatoshi KUBOKI, Nikken Sekkei Ltd.

Katsumi NIWA, Yasuharu HONDO and Yumi FUJII, Nikken Sekkei Research Institute

Abstract

A middle-sized office building (floor area : 5,645 m^2), nicknamed “Earth Port,” was renovated with the intention of making it a ZEB (“net-zero energy building”) by 2030. As a first step, the following technologies were introduced.

(1)Thermal network utilizing both solar heat and waste heat from gas cogeneration system (CGS) and gas engine driven heat pump (GHP).

(2)Bright-feeling lighting system and other measures to utilize natural sunlight

(3)Integrated power management system

The thermal and lighting environments were measured and analyzed to investigate the indoor environment as well as detailed energy consumption data.

The renovation resulted in a 37% reduction of primary energy consumption and a 45% reduction of CO_2 emissions compared with the average for tenant-occupied office buildings (baseline).

1. Introduction

In moving to realize a low-carbon society, there are strong demands for energy conservation and CO_2 emissions reduction in the commercial and residential sector, which accounts for about 30% of Japan’s final energy consumption and has rising CO_2 emissions. In particular, measures for the huge stock of existing middle sized buildings are urgently needed.

To address this, we renovated the Tokyo Gas Kohoku New Town Building, nicknamed “Earth Port”, toward making this into a Net-Zero Energy Building (ZEB). Specifically, we used renewable energies and state-of-the-art technologies to verify energy conservation and CO_2 emissions reductions measures, identified the issues, and examined solutions in an effort toward making this existing middle sized building into a ZEB.

This project was aimed at utilizing renewable energies, decreasing electric power consumption for lighting and otherwise thoroughly, reducing energy consumption on an individual-building basis as the first step toward making the Earth Port a ZEB by 2030. We took on the challenge of realizing additional reductions at this building, which had already achieved top-level energy conservation and CO_2 emissions due to installation of a gas engine cogeneration system (CGS) and the use of natural sunlight and ventilation[1]. After confirming and analyzing the effects from renovating the Earth Port under this project, the next step will be to aim at even greater efficiencies through an area energy network.

It is difficult to achieve ZEB on an individual-building basis for Japanese commercial buildings, which are generally located on small plots, so networking with neighboring buildings (area energy networks) is considered necessary. ZEB is defined as “a building that consumes zero or nearly zero energy on an annual net basis by reducing primary energy consumption in the building through enhanced energy efficiency performance of the building envelope and facilities, networking of neighboring buildings, on-site utilization of renewable energy, and so on” in Japan[2]. However, the detail of the definition hasn’t been standardized. Marszal et al[3]. reviewed existing ZEB definitions and the various approaches towards possible ZEB calculation methodologies and Kurnitski et al[4]. proposed an uniformed national implementation of EPBD recast. But it is still challenging to do ZEB calculation for networked buildings, some of them generating energy and sharing it each other. The next step of this project will include definition and methodology of ZEB calculation for networked and energy sharing buildings.

This project was selected as a “Demonstration Project for Next-generation Buildings Using Energy Efficiency Technologies” and subsidized by Japan’s New Energy and Industrial Technology Development Organization (NEDO).

2. Outline of the Renovation Works

Photograph 1 shows the Earth Port, when it was completed in 1996.

Table1 Overview of the Earth Port

Location	Yokohama City, Kanagawa Pref.
Completed	March 1996
Floor area	5,645m^2
Structure	SRC, RC, S, wood
No. of floors	4 stories above ground + 1 penthouse
Use	Offices, showroom

Photograph 1 Earth Port (1996)

The goal of the renovation was to reduce primary energy consumption by around 40% compared with a regular tenant building, and to verify the effectiveness of the following technologies. An overview of the renovation is shown in Figure 1.

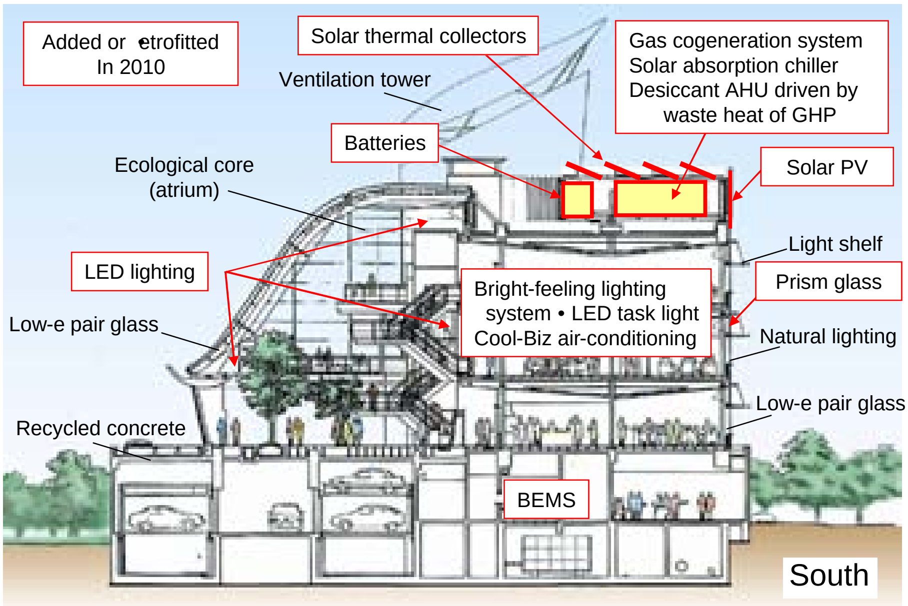


Figure 1 Overview of the renovation

2.1 Energy Conservation and CO_2 Reduction Air Conditioning System with Optimal Use of Solar Heat, CGS Waste Heat and GHP Chiller Waste Heat

The use of renewable energies is essential to improve air conditioning system efficiency toward realizing ZEBs. Among these, solar heat, which can efficiently utilize solar energy, is effective for air conditioning and other heat applications. It is important to develop heat utilization equipment that can use solar heat, as well as control technologies. This project formed a thermal network utilizing solar heat together with CGS waste heat and GHP chiller waste heat in an absorption chiller heater and in desiccant Air Handling Units (AHUs), constructing a high-efficiency air conditioning system. The system flow is summarized in Figure 2 .

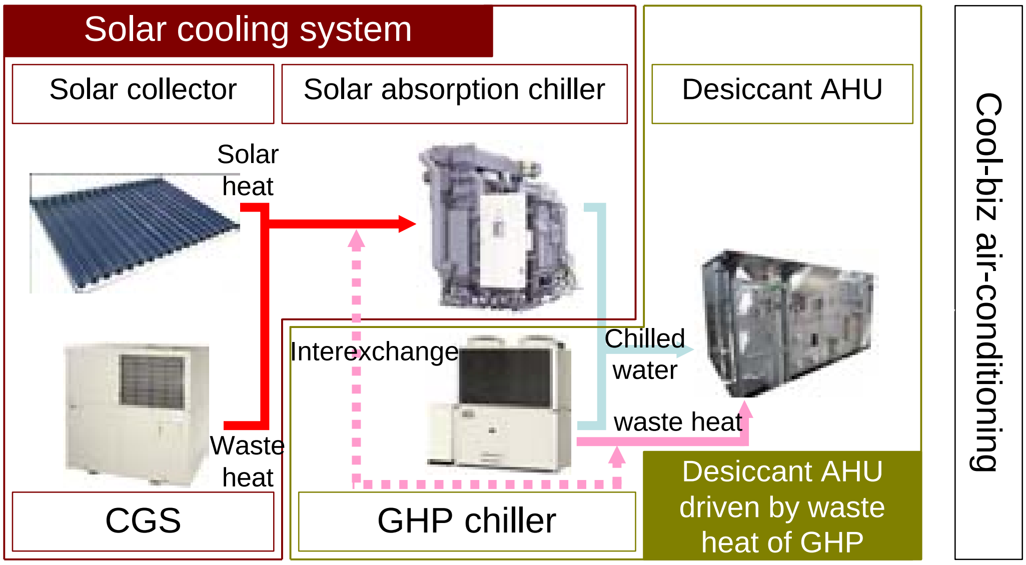


Figure 2 Air conditioning system flow

Solar thermal collectors with a rated heat output of around 100kW were installed on the roof. The system uses heat from these collectors, which varies depending on the weather, on a preferential basis. It is supported by CGS waste heat to provide stable air conditioning using a solar absorption chiller heater (a gas absorption chiller that can utilize solar heat). In this design, the system uses the solar absorption chiller heater and desiccant AHUs in a cascade flow, depending on the temperature of the hot water from the solar thermal collectors, to achieve greater efficiency through the maximum use of heat.

The solar thermal collectors use doubled-walled concentric glass tubes, which have a vacuum between their two layers. Together with the reflectors, glass tubes make high-efficiency heat collection possible because of its high insulation performance.

Desiccant AHUs are used as air conditioning equipment, with the goals of conserving energy and reducing CO_2 emissions while also providing comfortable air conditioning by controlling humidity and maintaining a relatively high indoor temperature. By using the GHP chiller waste heat as the heat source for regenerating the desiccant rotor, comfortable air conditioning is achieved without using any additional energy. This project is the first example of effectively using GHP waste heat during cooling.

The project also adopted “Cool chairs” on an experimental basis to make the desiccant “Cool Biz” air conditioning more effective. The Ministry of Environment Cool Biz campaign aims at reducing energy consumption by limiting air conditioning use. “Cool chairs” are chairs with battery-driven fans. The ventilation fan at the front of the chair dissipates the heat from the chair seat, and the fans on the armrests blow air directly on to the body (the airflow amount and direction can be adjusted). In offices where different types of people work, those who are more sensitive to heat could use cool chairs to minimize discomfort even in rooms where the temperature is set relatively high. The cool chair electric power consumption at maximum fan speed is only about 5W, and the fans are turned on and off by sitting down and standing up, so they cannot be left running accidentally. The increased energy use from using cool chairs is minimal compared with the energy saved by reduced air conditioning use by setting the thermostat at a higher temperature.

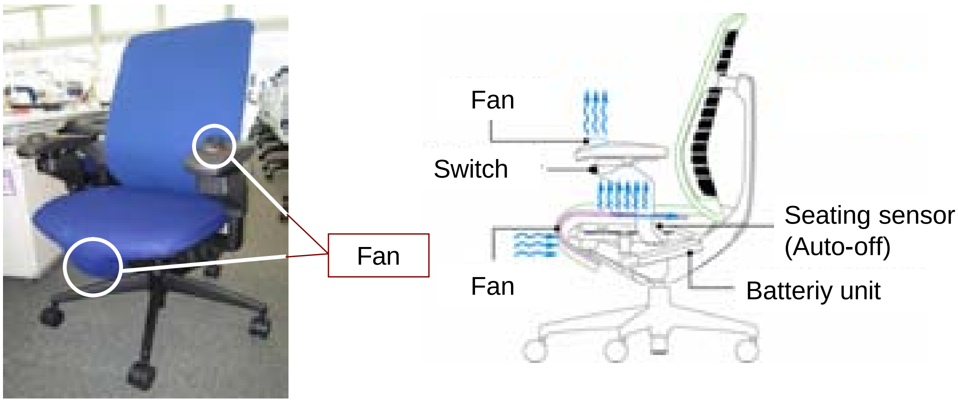


Figure 3 Cool chair

2.2 Bright-feeling lighting system and other measures to utilize natural sunlight

The measures to conserve energy use in lighting system have more universal applications compared with the other measures. To horizontally roll out these measures to other existing middle sized buildings, beyond just introducing high-efficiency lighting, responding to changes in applications, layouts and other usage conditions are also important to continuously maintain the effects.

In this project we expanded the use of natural sunlight, which had already been adopted, introduced "bright-feeling" lighting that emphasizes a feeling of brightness in ambient areas along with high-efficiency LED lighting for task lighting. Lightings were replaced to LED lighting in common areas. We also installed optimal control system through motion sensors on-off control and illuminance control by area, in order to verify technologies that conserve energy, respond flexibly to layout and other changes and maintain continuous effects.

Figure 4 presents an image and a cross-section of the bright-feeling lighting, as well as the luminance distribution and photos before and after the improvements. The bright-feeling lighting installed reflectors to the existing lighting features to illuminate the ceiling and impart a feeling of brightness throughout the room. Figure 4 shows that users perceived a similar brightness (Feu• 14) on their desks at 435Lx with the reflectors as they did at 684Lx without the reflectors, meaning significant amount of electricity for lighting was saved.

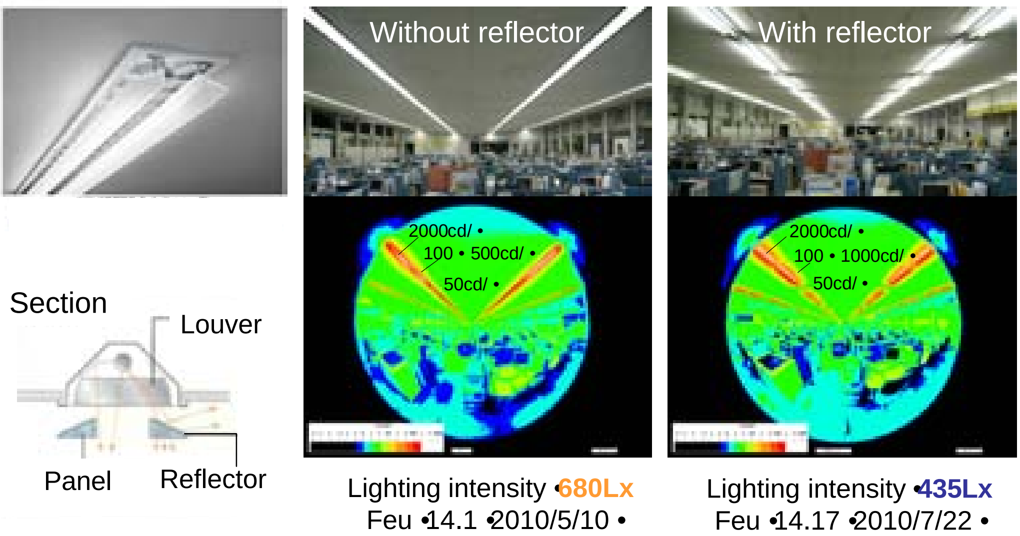


Figure 4 Bright-feeling lighting system

While the desk-top illuminance in ambient areas was set as 300Lx during the summer of 2011 as an electricity conservation measure, during the daytime natural sunlight almost always provided sufficient light and users almost never used the task lights provided for lighting at hand. This method is deemed extremely effective to reduce electric power consumption for lighting at existing buildings.

2.3 Integrated Power Management System Combining Photovoltaic Power Generation with High-efficiency CGS, etc.

Improving the economics of photovoltaic power generation and stabilizing electric power supply when introduced on a large scale are important issues for spreading photovoltaic power and turning buildings into ZEBs. To address these issues, while the normal approach is to combine photovoltaic power generation with storage batteries, this project makes the further addition of CGS and introduces an integrated power management system to build a stable energy conservation type electricity supply system which compensates for the demerits of battery function deterioration, and charge and discharge loss. This works at (1)improving the economics through the effect of reducing demand, and (2) stabilizing the photovoltaic power output via cooperative control of the CGS and the batteries. The evaluation results of this demonstration will lead to component technologies important for building a smart area energy network that conserves energy and reduces CO_2 emissions throughout the area.

A total of 21.5kW of photovoltaic panels were installed on the southern and western sides of the rooftop sound barrier wall. The system works to secure the demand reduction effect and stabilize overall electric power output by compensating for the relatively short-term fluctuations of photovoltaic electric power generation with the batteries and for the relatively long-term fluctuations with the CGS. Figure 5 presents an outline of the integrated power management system.

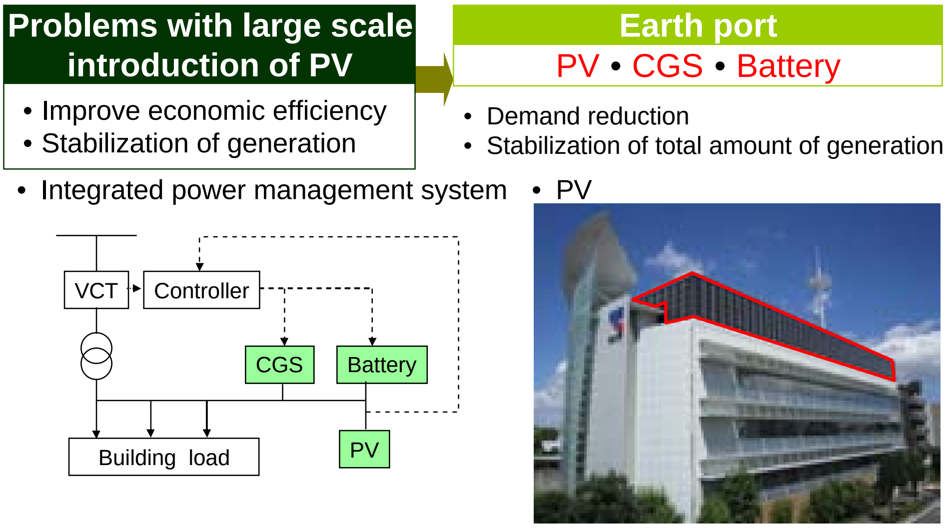


Figure 5 Integrated power management system

3. Energy Consumption

Figure 6 presents the primary energy consumption per unit floor area over the 12 months from October 2010, when the new system began regular operation through September 2011 compared with the fiscal 2004 level prior to the renovation and with a baseline level. The baseline shows the actual fiscal 2005 figures for tenant buildings published by the Tokyo Energy-Saving Program, Tokyo Metropolitan Government.

The primary energy consumption per floor area at the Earth Port after the renovation was 1,585MJ/m^2, which is a 17% reduction compared with before the renovation and a 37% reduction from the baseline. Comparing the energy consumption details before and after the renovation works, the energy consumption for air and water conveying systems increased. The increase for the solar cooling system's hot water cycling system was about 4%, and we investigated the causes. We determined that the air volume output by the Variable Air Volume (VAV) system always ran near the maximum, and that the energy used by the air conditioning fans had greatly increased. The cause was that in this building, which uses the ceiling chamber system, seal leaks had appeared along with the passage of time. If there were no seal leaks and the energy consumption for the air and water conveying systems had remained the same before and after the renovation, the reduction in primary energy consumption from the baseline figure would have been around 41%. We are presently examining ways of fixing the leaks.

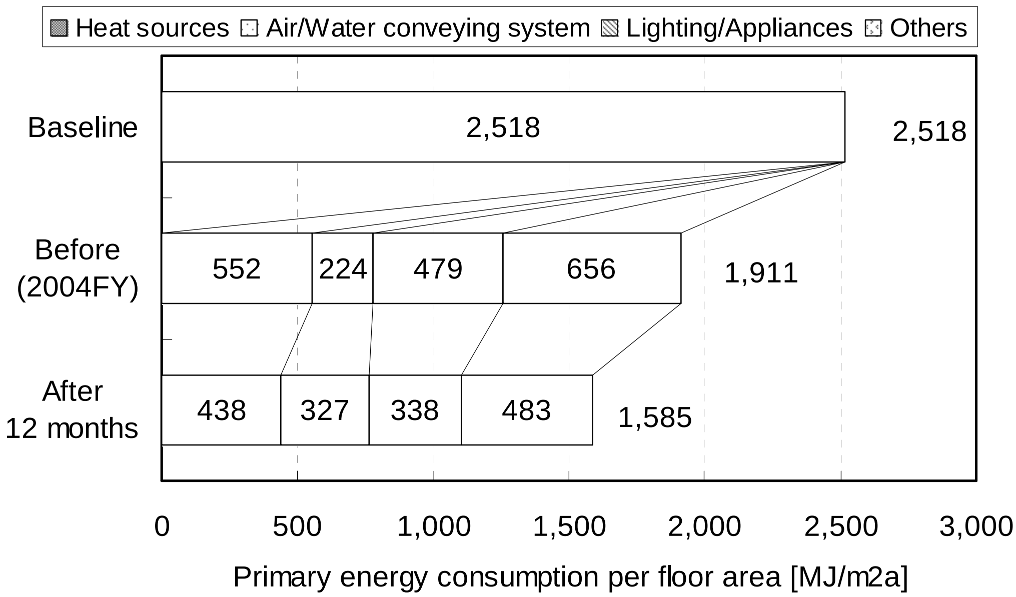


Figure 6 Primary energy consumption per floor area

Figure 7 presents the peak electricity demand per floor area in 2009 before the renovations and in 2011 after the renovations compared with that at a regular office building. Because the Earth Port had already introduced CGS and gas air conditioning before the renovation, the peak electricity demand was already a reduction of about 39% from a regular office building. In 2011, adding the effects from the higher overall systems efficiencies under the renovation and tenant energy conservation efforts, the peak electricity demand was reduced by nearly an additional 35%, for a total reduction of about 60% compared with a regular office building. This shows that the CGS and gas air conditioning greatly contributed to reducing the peak electricity demand in summer and to demand leveling.

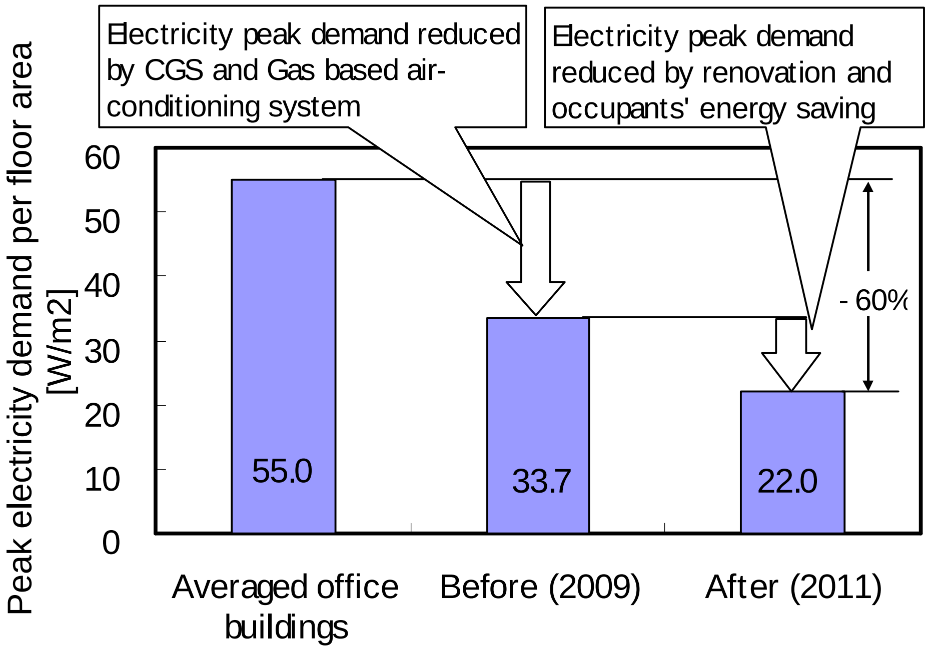


Figure 7 Peak electricity demand per floor area

4. Indoor Environment

We measured the indoor temperature and illuminance distribution to confirm the indoor environment formed by the air conditioning and lighting changes due to the renovation. The measurements were conducted on a room being used as an office with dimensions of 32m (east-west) by 13.5m (north-south). The measurements were conducted with the systems set for a desk-top illuminance of 300Lx in ambient areas and a room temperature of 26ºC.

Figure 8 presents the desktop illuminance distribution on cloudy and sunny days. The figure indicates that natural sunlight from the south windows and the north-side atrium is being effectively used on both cloudy and sunny days. The northeast corner does not effectively use natural sunlight, and has some areas where the ambient illuminance is insufficient. This is apparently because the tenant removed some of the lighting fixtures to conserve electricity. This should be improved by reconsidering the method for thinning out the lighting fixtures, based on the results of this measurement.

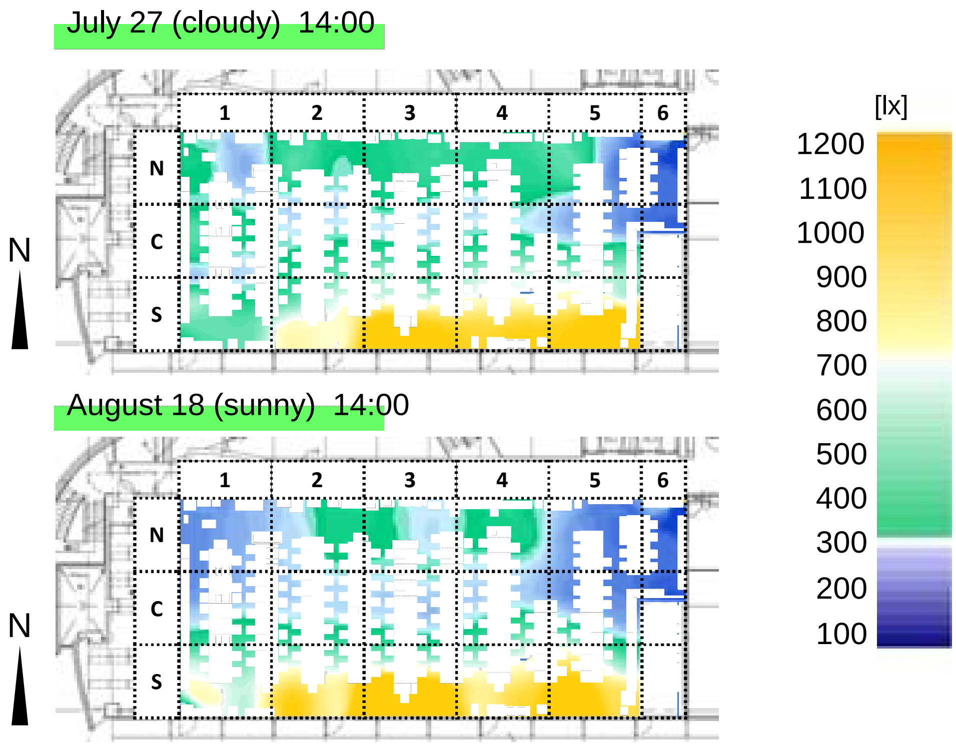


Figure 8 Desktop illuminance distribution

Figure 9 shows the temperature distribution 1.1 meters above the floor on both cloudy and sunny days. On cloudy days, the temperature increases in areas on the west side of the room where there are many people. On sunny days, the temperature increases in areas on the south side because of the effect of the sunlight. In both cases, the indoor temperature is uneven and the temperature control insufficient because of the leaks in the seals in the ceiling chamber system air conditioning mentioned in section 3.

As explained above, while the indoor environment is within the acceptable range, further improvements are expected to provide an even more comfortable environment.

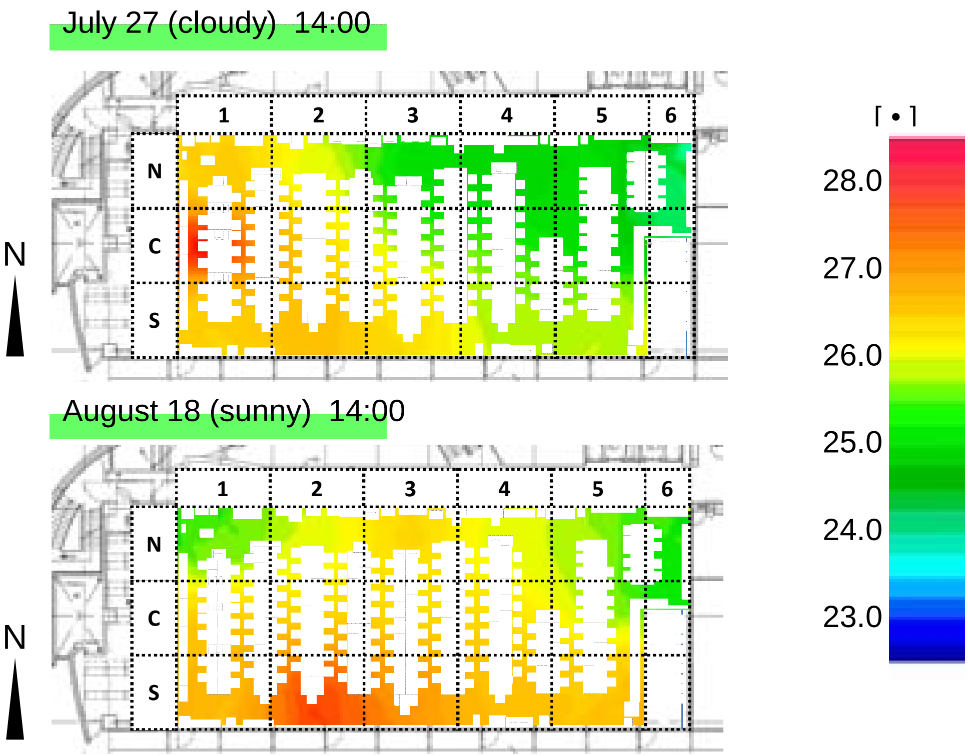


Figure 9 Temperature distribution

5. Future Outlook

These renovation works reduced primary energy consumption by around 37% from the baseline level, as the first step toward making the Earth Port a ZEB. Additional reductions should be possible by repairing the above-mentioned seal leaks and further optimization of operations. The technologies verified as effective through this renovation will be considered for application to existing middle-sized buildings without advanced energy conservation measures.

As the next stage for the Earth Port, we will introduce even more high-efficiency equipment and examine energy reductions from an area energy network. If the Earth Port and neighboring buildings with a different demand pattern could share larger scale solar thermal collection, photovoltaic and cogeneration systems and give each other heat and electricity, the combined demand would level out, and it would be possible to introduce large-scale high-efficiency equipment and operate them near rated capacity to achieve further high efficiencies. Also, when the sky is clear on a Sunday and the Earth Port—which is used mainly as office—generates more energy than it needs, that energy could be effectively used in neighboring buildings. We will work toward achieving ZEB by 2030 in this manner, not for the Earth Port on a stand-alone basis but rather through energy sharing among a group of buildings in an area energy network while reducing consumption.

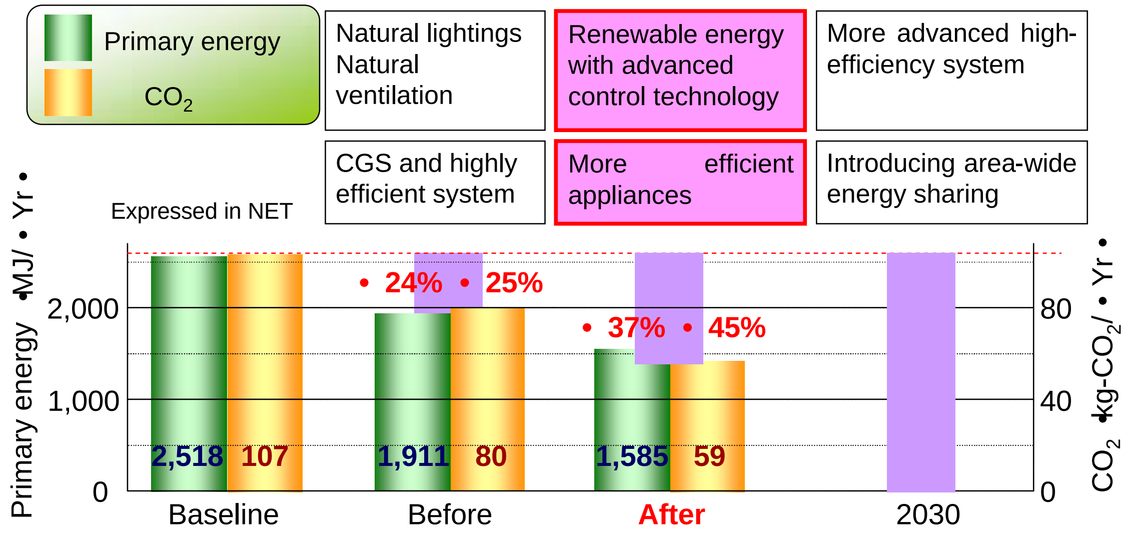


Figure 10 Image towards ZEB

References

[1] Osamu Shibata, EARTHPORT:Tokyo Gas Kohoku New Town Building • An Office Building with Life-cycle Energy Saving Features • , Eco Design'99

[2] Agency for Natural Resources and Energy Japan, Interim report of Committee on Realization and Dissemination of ZEB (in Japanese), 2009

[3] A. J. Marszal, et al., Zero Energy Building – A review of definitions and calculation methodologies, Energy Buildings, 2011

[4] J. Kurnitski, et al., How to define nearly net zero energy buildings nZEB – REHVA proposal for uniformed national implementation of EPBD recast, REHVA, vol.48, Issue 3, 2011

Energy Retrofit of Commercial Buildings: A Case Study on ERGO Building

N. Aste, R.S. Adhikari, C. Del Pero and L.C.Tagliabue

Politecnico di Milano. Dept. Building Environment Science and Technology (BEST)

Abstract

It is well known that in developed countries the energy consumption of the building sector accounts for a 20–40% of the total energy consumption, therefore, improvement in building energy performance is considered an urgent commitment in order to reduce the energy import dependency and comply with the Kyoto Protocol. Commercial buildings are responsible for a significant share of the energy requirements of European Union countries. Related consumptions due to heating, cooling and lighting appear in most cases very high and expensive.

Architectural renovation of existing buildings could provide an opportunity to enhance their energy efficiency through improvements in the envelopes and energy supply systems. In general there is a lack of well established methods for retrofitting but, if a case study reaches to effective results, the adopted strategies and methodologies can be successfully replicated for similar kind of buildings.

In this paper an interesting example of office building energy retrofit is presented. The analysis and simulations of energy performance before and after the interventions, along with measured data on real energy performance, demonstrate the validity of the applied approach. The specifically developed design and refurbishment methodology, presented in this work, could be also assumed as a reference in similar operations. The analyzed case study is represented by the Italian headquarter of a major insurance company in northern Italy (Milan), which recently has been transformed in a high energy performance building. Recently, this project has been awarded in the international competition Zerofootprint Re-Skinning Awards, supported by UN-Habitat and U.S. Green Building Council, with a specific mention for replication of the retrofit methodology.

Introduction

Over the past decade, rapid growth of energy consumption and CO_2 emissions in the building sector has made energy efficiency a priority objective in various countries by developing new building regulations and certification schemes targeting at minimum energy performance requirements [1]. In this respect, the European Commission has decided to cut drastically CO_2 emissions and to increase the share of renewable sources within total energy consumption in building sector. In the European Union, the recently adopted EPBD recast [2] states that by the end of 2020 all new buildings should be "nearly zero energy buildings", i.e. with very high energy performance and their energy requirements covered by renewable energy sources to a significant extent. The further target is to achieve the goal of "net zero energy buildings" in a few years.

Considering the quantitative impact of the existing European building stock and its average energy efficiency, by making interventions only in new constructions, it would be impossible to achieve the objectives imposed by EU, and therefore, they must face the issue of the energy retrofit of existing buildings. In this context, the 2010/31/EU Directive of The European Parliament and of The Council promotes the improvement of the energy performance of buildings within the Union, taking into account outdoor climatic and local conditions, as well as indoor comfort requirements and cost-effectiveness [2]. It is useful that the energy performance of buildings could be calculated on the basis of a methodology which should be based not only on heating requirements, but should cover the whole annual energy performance of a building, including summer cooling requirements. During recent years the number of air-conditioning systems in European countries has increased very fast [3]. This factor creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance. It is then necessary to consider carefully also the strategies which enhance the thermal performance of buildings during the summer period, promoting measures which avoid overheating (such as shading and thermal mass of the building envelope).

In Europe, the commercial sector is among the fastest growing energy demand sectors and is projected to be 26% higher in 2030 than in 2005, compared to only 12% for residential buildings. The growth of energy needs in the building sector is driven by the evolution of non residential buildings [4]. Specific energy consumption rates depend on several factors, such as climatic, economic, social, geographic contexts, and thus they could be characterized by widely different values. It has to be noted that the measures to improve the energy performance of buildings should pay particular attention to the cost-effectiveness of the interventions, otherwise a negative impact may result on the property market. For these reasons the opportunity to refer to best practice examples at international, national and local level is of primary importance. If a case study reaches effective results, the adopted strategies and methodologies can be successfully copied in similar interventions.

In this paper an example of energy-conscious refurbishment is presented. It regards an existing office building, of which the renovation demonstrates how this type of intervention could be convenient not only from an energy efficiency point of view of, but also, more generally, from an economic one. Recently, this project has been awarded in the international competition Zerofootprint Re-Skinning Awards, supported by UN-Habitat and U.S. Green Building Council, with a specific mention for replication of the retrofit methodology.

Case study description

The case study building is the headquarters of a major insurance company in northern Italy (Milan). The original structure built in 1998 was a typical commercial building, arranged in two rectangular blocks (a low-rise structure and a tower) with a total gross volume equal to 45'500 m^3, of which 33'326 m^3 are occupied by offices and other conditioned spaces. A pictorial view of the building before energy retrofit is shown in Fig.1.

Figure 1 Case study building before energy retrofit

Building envelope

In general, the construction quality of the building was rather poor, especially in terms of durability, thermal insulation and energy efficiency, representing a widespread standard in Italian commercial architecture at the end of the 1900s. The opaque parts of the external facades were built in layers of bricks with thin insulation inside and covered with clay tiles, while the transparent surfaces were made of bronze double-glazing with a low light transmission factor. Some portions of the opaque facades were covered with spandrel panels-reflective glass coupled with an insulating panel on the inner part.

As a result, energy consumption for heating, cooling and artificial lighting was very high, negatively impacting on operating costs.

Opaque parts of the facades are in general constructed with two types of brick. The outer package is made of 12cm thick hollow blocks with vertical holes, while the inner layer is composed of hollow blocks with a thickness of 8cm and horizontal holes. Between the two layers are interposed an insulation layer and an air gap, with total thickness varying from 5 to 7.5cm, because of the unevenness of the existing envelope surface. The insulating material can be rock wool or polystyrene, with variable thickness from 2 to 3cm. Figure 2 shows the position of different vertical envelope elements.

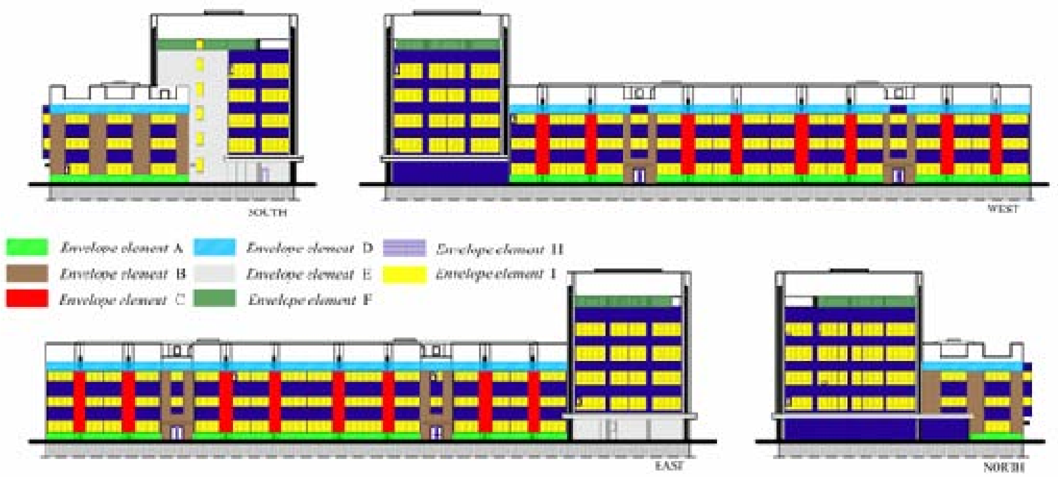


Figure 2 Position of different vertical envelope elements

For opaque envelope, the global insulation level of the building is low, with an average value of thermal transmittance equal to 0.8 W/m^{2}K for vertical opaque walls and 0.48 W/m^{2}K for horizontal roofs. The estimated U-values for each envelope element are shown in Table 1.

Table 1 U-values of envelope elements before energy retrofit

Envelope element	**U (W/m^{2}K)**
A - External wall	0.797
B - External wall	0.617
C - External wall	0.607
D - External wall	2.082
E - External wall	0.570
F - External wall	0.577
H - External wall	0.472
L - Ground Floor	0.921
M- Roof	0.483

The transparent envelope is constituted by double glazed windows with external bronze tempered glasses having a thermal transmittance equal to 1.8 W/m^{2}K. The thermal and optical properties of the glazed surface are reported in Table 2.

Table 2 Main glasses characteristics before energy retrofit

	Type-I	Type-II
Thermal transmittance (W/m^{2}K)	1.8	1.9
Light transmission factor (%)	29	27
Exterior light reflection factor (%)	43	43
Solar factor (%)	35	34

HVAC system

The HVAC plant is composed of a two-pipe water distribution system, which has hydraulic fan coils as terminal units, and a dual-duct air system. The entire building has been divided into three independent parts, heated and cooled by three HVAC plants. In particular, the different systems analyzed by the survey are summarized as follows:

- Heating: Three natural gas boilers producing hot water at 65°C, for a total nominal thermal power equal to 1’200 kW.
- Cooling: Seven air-cooled electric chillers producing cooled water, for a total nominal cooling power equal to 840 kW.
- Air handling: Three dual-duct air handling units for a total capacity of 40’000 m3/hour.
- DHW system: electric boilers with a specific electric power equal to 1.2 kW, placed in the different toilets of the building, for a total power of 14.4 kW.

Moreover, also for non-HVAC/DHW plant and equipment (lighting, computing, printing etc.), all information useful for energy assessment has been collected through an inventory. This method has allowed the possibility to precisely determine the total electrical power and operating periods associated to different categories of appliances.

In 2007, a serious and premature degradation of the facades lead to the need of a major renovation of the building envelope. This would have caused a heavy economic burden for the company, which had not yet amortized the cost of the building. To resolve this problem it was decided to couple the restoration works with energy efficiency retrofit measures by applying the analysis and intervention methodology explained in this paper.

Energy retrofit strategy

All retrofit strategies adopted for energy rehabilitation of the case study building are shown schematically in Fig. 3. The first working-step involves envelope refurbishment, related to transparent and opaque surfaces, according to the hereafter described phases.

Vertical opaque walls rehabilitation

Opaque vertical walls and spandrel elements have been refurbished, adding insulation layers and a new exterior finish, made with a clear marble stone layer (envelope element A to F) and an aluminum cladding layer (envelope element H). In particular, a rock wool layer with 10cm thickness and a 0.034 W/mK thermal conductivity has been added to all vertical surfaces covered with stone, while behind aluminum cladding a 4cm polystyrene layer with 0.039 W/mK thermal conductivity has been placed.

Figure 3 Adopted energy retrofit strategies

In both cases an air gap has been maintained, creating a ventilated façade, able to increase the thermal performances of the building [5]. Moreover, the presence of a 3 cm-thick stone layer allowed to increase building thermal mass, with a considerable decreasing on periodic thermal transmittance and increasing of building energy performances [6].

Roof insulation

A 4cm high layer of cellular glass has been placed on the entire roof of the building; also in this case no particular changes have been made to the inner part of the envelope because only the outside layer has been modified. Table 3 shows estimated improved U-values for each vertical envelope components after energy retrofit.

Table 3 U-values of envelope elements after energy retrofit

Envelope element	**U (W/m^{2}K)**	**Improvement (%)**
A - External wall	0.234	70.6
B - External wall	0.216	65.0
C - External wall	0.215	64.6
D - External wall	0.286	86.3
E - External wall	0.210	63.2
F - External wall	0.211	63.4
H - External wall	0.289	38.8
M- Roof	0.318	34.2

Glass replacement

All window glass has been substituted with extra-clear double-glazing filled with argon. Metallic frames have been maintained because they are still considered efficient and in order to simplify the intervention. New glazing has a 1.3 W/m^{2}K thermal transmittance, a 80% light transmission factor and a solar factor equal to 66%.

Solar shading system

A dynamic solar shading system has been placed outside all windows in order to achieve a substantial improvement in the level of visual comfort in the workplace. It is composed of three different technologies; the first one comprises of compact moving shades, these are profiles with an ellipsoidal section of the width of 15cm, and placed with a spacing of 15.5cm; the axis of rotation of the blinds is in the centre with respect to profile section. These kinds of shades are located on the windows of every floor, excluding the basement floor, in the south face of the tower, in the east face of the lower block and in the west face of the lower block. The second technology comprises large moving shades: a larger blade of 40cm width is placed on top of compact shades and has and independent moving system. The main function of this shade is to deflect daylighting on the roof of working places. These blades are present in the same windows as compact blades.

The last shading system is composed of adjustable Venetian blinds, placed on the entire south façade and on the ground floor of east and west facades of the lower block; moreover they are placed on the tower block on east and west façades. The blinds can be tilted, as needed, according to one of the following positions, defined by the angle of inclination of the longitudinal axis of the elliptical cross section with respect to the horizontal plane: 0°, 37°, 45°, 70°, 0° (shadowing) raised and packaged, -20° (deflecting) as shown in Fig. 4.

Figure 4 Dynamic solar shading system – compact and large moving shades

Blades and blinds are controlled by an analytical-empirical logic, which calculates the position of the sun and determines the optimal hourly configuration of shading systems, such that direct solar radiation is totally blocked or effectively controlled. Such system allows to optimize daylight contribution on working areas, minimizing solar gain during cooling seasons [7].

Double-Skin facades

On the south vertical surface of the lower block of the building, three dynamic double-skin facades have been installed (Fig. 5). Facades are equipped with frontal opening glazing, regulated by an automatic control system that opens when, during the summer season, the air temperature inside the double-skin becomes higher than the ambient temperature. This way an air flux is generated from the bottom part to the upper part of the façade.

A 3 kWp BIPV plant has been integrated on the roof of a double-skin façade, allowing both to produce approximately 3'250 kWh_e/year and to partially shade the south-facing windows. The PV plant is constituted of custom-made glass to glass PV modules specifically designed for the analyzed application, connected to two DC/AC converters.

Figure 5 Double-skin facades

Energy performance analysis

In order to precisely analyze building energy performance and to scientifically define energy saving strategies, a computerized model (Fig. 6) has been set-up through the specific simulation software DesignBuilder based on, by which a dynamic-regime energy calculation have been carried out through EnergyPlus [8].

So, including in the model the morphological, technological and plants building features, the working and occupation profiles and climatic features of the site, it has been possible to get a computerized overview of the energy behaviour of the building.

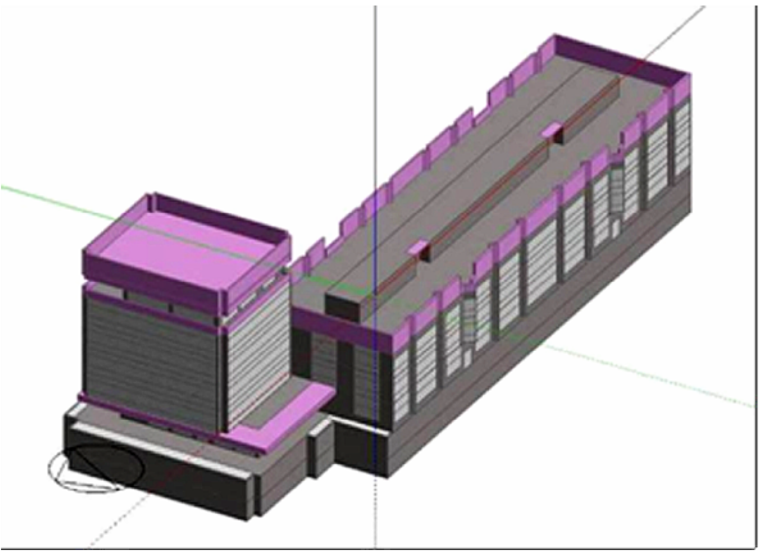


Figure 6 Designbuilder building model

Moreover, in the energy simulation, many detailed parameters can be calculated, such as temperatures, hourly fuel consumptions and internal heat gains.

Measured consumption analysis

In order to check performance enhancement during and after the interventions, natural gas and electricity consumption monitoring has been continuously carried out and analyzed.

As an example, Table 4 shows the values of natural gas (NG) consumption during the heating period. Considering that variable climatic conditions can influence measured consumptions (e.g. colder or warmer winters), heating degree days (HDD20) have been calculated and specific energy consumption (kWh/ HDD20) has been estimated. These data are the most significant to demonstrate the obtained energy benefits.

Table 4 – Total and specific natural gas consumptions during and after intervention

Month	2006-2007 (Before retrofit)			2007-2008 (During retrofit)			2008-2009 (During retrofit)			2009-2010 (After retrofit)		
	NG consump.	DD		NG consump.	DD		NG consump.	DD		NG consump.	DD	
	kWh	-	kWh/DD	kWh	-	kWh/DD	kWh	-	kWh/DD	kWh	-	kWh /DD
Oct	17’803	49	365	11’524	51	227	12’084	73	166	21’879	169	129
Nov	76’437	283	270	96’653	362	267	71’991	331	217	61’427	331	186
Dec	118’237	448	264	96’701	528	183	150’309	523	287	131’974	539	245
Jan	105’355	428	246	157’425	473	333	162’764	581	280	114’608	533	215
Feb	93’642	368	254	78’727	407	194	94’288	448	210	102’885	433	238
Mar	68’543	297	231	68’258	297	230	60’430	363	166	75’269	348	216
Apr	45’838	73	626	41’154	123	335	19’029	82	232	26’762	187	143
Total	**525’854**	**1’947**	**270**	**550’440**	**2’240**	**246**	**570’893**	**2’401**	**238**	**534’803**	**2’540**	**211**

For electricity, a similar approach has been carried out, normalizing energy consumptions on cooling degree days (CDD20). Anyway, considering that electricity is not related just to cooling demand, for each year the average monthly electrical consumption during non-cooling season has been calculated and assumed as non-cooling electrical base load, subsequently detracted from total monthly electricity needs during the cooling period.

It is important to remember that, although the cooling set point of the building is 26°C, the CDD20 parameter is based on average daily temperature and it gives information on the climatic conditions than can generate cooling needs on the building also for few hours. The results for cooling period are shown in Table 5.

Table 5 Total and specific electricity consumptions for cooling purposes during and after intervention

Month	2006-2007 (Before retrofit)			2007-2008 (During retrofit)			2008-2009 (During retrofit)			2009-2010 (After retrofit)		
	Tot	CDD_{20}	Spec.	Tot	CDD_{20}	Spec.	Tot	CDD_{20}	Spec.	Tot	CDD_{20}	Spec.
	kWh_e	-	kWh_e/CDD_{20}	kWh_e	CDD_{20}	kWh_e/CDD_{20}	kWh_e	CDD_{20}	kWh_e/CDD_{20}	kWh_e	CDD_{20}	kWh_e/CDD_{20}
May	34’510	39	885	9’668	38	254	17’711	41	432	12’320	23	536
Jun	55’393	83,6	663	28’309	86	329	31’486	96	328	27’676	90	308
Jul	85’931	171,2	502	50’816	120	423	47’759	170	281	51’956	202	257
Aug	39’155	93,4	419	30’662	118	260	36’664	188	195	27’480	103	267
Sep	25’763	23	1’120	13’308	39	341	19’817	41	483	12’500	18	694
Total	**240’752**	**410**	**587**	**132’763**	**401**	**331**	**153’437**	**536**	**286**	**131’932**	**436**	**303**

Observing the above mentioned data, it is possible to assert that a substantial decrease in monthly specific energy consumption has been recorded.

It has to be noted that the above calculated decrease in HVAC consumptions is affected also from variations on internal loads and solar gains, caused by significant reduction of artificial lights, due to the glazing substitution and related to the solar shading system installation.

For this reason it is necessary to quantify the seasonal reduction obtained on lighting consumption; the calculation has been made by analyzing different working periods of artificial lights, estimated by specific surveys made on working spaces. The final result is that, yearly, the energy demand for this purpose is diminished from approximately 320 MWh to 170 MWh. It must be considered that reduction on artificial lighting becomes a benefit during cooling season but it turn into a disadvantage during heating period.

The final primary energy consumption figures before and after energy retrofit for the case study building are shown in Fig. 7. As can be seen, the total primary energy demand passes from 1’870 MWh to 1’130 MWh, with a decrease equal to approximately 40%.

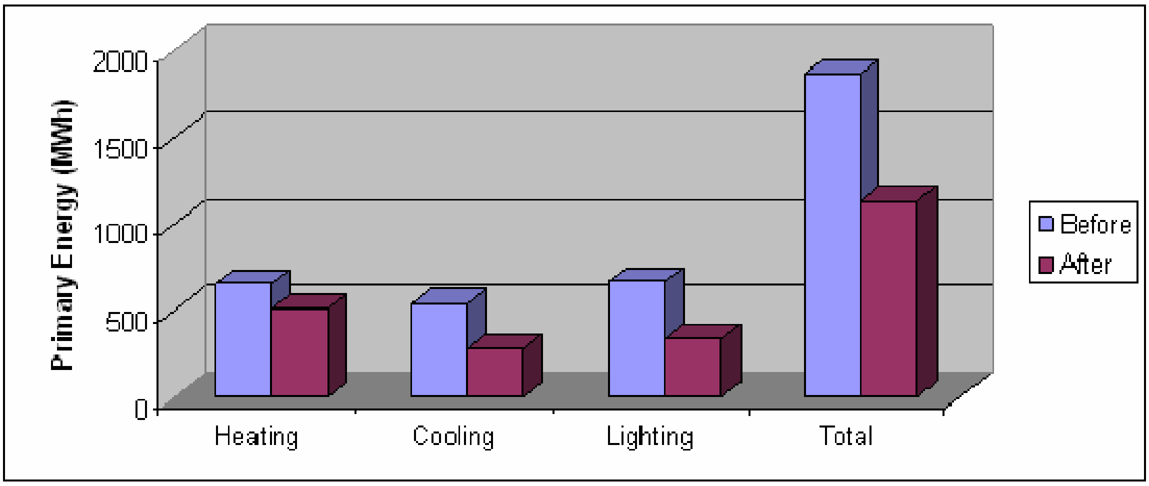


Figure 7 Total primary energy saving normalized on mean values

It must be noted that up to now no interventions were made on the HVAC plant, so energy consumptions due to air handling, electric auxiliaries (fan, pumps) etc. were supposed to be reduced proportionally to the obtained decrease on envelope’s thermal energy need.

Conclusions

The need to reduce energy consumption in buildings requires effective interventions in real estate, with a particular focus on commercial buildings because, as described above, this is a relatively large and growing sector. There is an extensive documentation and literature on new buildings characterized by high energy performance, but in general there are still no well established methods for retrofitting.

Effective interventions can be based on references provided by case studies. Within this work an articulated design and refurbishment methodology is presented, applied to a real case study, along with the results obtained in terms of energy savings. The combination of renovation and building energy retrofit, if organized in a careful and integrated approach, produces remarkable results. In the presented case, a reduction in primary energy consumption by 40% was measured, by intervention realized just on the building envelope. Such reduction was verified by comparison of actual energy demands measured before and after intervention and precisely during 2007 and 2010.

Thanks to the energy model used in this work, detailed intervention costs and broad obtainable energy performances were calculated for different Energy Retrofit Measures, obtaining an accurate evaluation of the different energy saving potentials and defining the final energy retrofit design for the analyzed building. Further detailed economic analysis are being developed, comparing cost/effectiveness of the proposed retrofit in comparison with no intervention and demolition/replacement scenarios, in order to demonstrate that on building lifespan the retrofit option has lower life cycle economic costs [9].

In conclusion it should be mentioned that the case study building has been awarded recently as a finalist in the international competition Zerofootprint Re-Skinning Awards, supported by UN-Habitat [10] with a specific mention for replication of the proposed retrofit.

References

[1] EPBD, *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings*, Official Journal of the European Union.

[2] EPBD recast, *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Official Journal of the European Union, 18/06/2010.

[3] Industry Experts, Central Air Conditioning Systems - A European Market Overview, 2010. http://marketpublishers.com.

[4] Spyropoulos G.N. and Balaras C.A., *Energy consumption and the potential of energy savings in Hellenic of•ce buildings used as bank branches—A case study*. Energy and Buildings 2011; 43:770–778.

[5] Ciampi M., Leccese F. and Tuoni G., *Ventilated facades energy performance in summer cooling of buildings*, 2003, Solar Energy 75: 491–502

[6] Yang L. and Li Y., *Cooling load reduction by using thermal mass and night ventilation*, 2008, Energy and Buildings 40: 2052–2058.

[7] Tzempelikos A. and Athienitis A.K., *The impact of shading design and control on building cooling and lighting demand*, 2007, Solar Energy 81: 369–382

[8] Crawley D.B., Lawrie L.K., Pedersen C.O., Winkelmann F.C., Witte M.J., Strand R.K., *Energyplus: an update, Proc. International Symposium of SimBuild*, August 4–6, 2009, Boulder (CO, USA): International Building Performance Simulation Association; 2009.

[9] Dong B., Kennedy, C. Pressnail K., *Comparing life cycle implications of building retrofit and replacement options,* 2005, Canadian Journal of Civil Engineering 32: 1051-1063.

[10] Zerofootprint Re-Skinning Awards 2011, Toronto. http://reskinningawards.com

SusStations Project – A New Generation of Sustainable Railway Stations

Joanna French

Transport Regeneration Ltd, Project Coordinator, SusStations Project, on behalf of the Lead Partner, Lancashire County Council

Abstract

The SusStation Project aims to deliver and promote a new generation of sustainable, low carbon, railway stations. It is led by Lancashire County Council and involves rail industry partners from across North West Europe. The project is also supported financially by the European Union's Interreg IVB North West Europe programme, which aims to promote transnational cooperation.

The project includes demonstration projects at stations, currently between planning and completion stages. These demonstration projects provide learning material and are accessible to the general public. Also, an Assessment Tool, to inform future decisions about building, planning and operating sustainable stations. The Tool is intended for use by station infrastructure owners and operators and local/transport authorities who specify station schemes.

With the first investment, Accrington EcoStation, now complete, and through sharing of transnational knowledge, preliminary conclusions are available. Energy use at stations can be substantially reduced; at Accrington it was halved. Renewable energy schemes can be helpful in achieving low carbon stations. However, carbon neutral stations are not, in the project's experience, practically achievable. Sustainability should not be at the expense of passenger comfort. Infact, the Accrington investment is successful because station improvements have led to a 10% increase in passenger use. This means more low carbon travel by train. Good practice towards sustainable stations has been identified e.g. integrating sustainability from the outset, involving local communities in their station and use of local materials. For the future, SusStation participants are keen to see how life cycle costs are integrated into investment decisions.

1. Context – the Interreg IVB North West Europe Programme

INTERREG IVB NWE is a financial instrument of the European Union's Cohesion Policy. It funds projects which support transnational cooperation. The aim is to find innovative ways to make the most of territorial assets and tackle shared problems of Member States, regions and other authorities. The SusStations project has been developed and implemented in this context.

2. Objectives

The SusStations project aims to achieve a new generation of sustainable, low carbon stations. Rail is a high risk and highly regulated sector; to date there is very limited progress with introducing sustainable measures to station buildings. This is a lost opportunity because there are so many stations at the heart of communities they serve; their accessibility makes them ideal demonstration locations. This project, funded by the Interreg IVB North West Europe programme is helping to change the rail industry and tackle climate change.

The project runs from 2009 to end 2013.

The project logo is at Figure 1 below:

Figure 1: SusStation logo

The project website (hosted by Deutsche Bahn) is at: www.susstations.org/

3. Participants

The project participants are as follows:
- Lancashire County Council (Lead Partner)
- ProRail (Partner)
- Deutsche Bahn Station & Service AG (Partner)
- Northern Ireland Railways/Translink (Partner)
- Boulogne sur Mer Developpement Cote d'Opale (Partner)
- Northern Rail Ltd (Subpartner)
- NS Groep NV (Subpartner)
- SAS ecoquartier de la gare de Boulogne sur Mer (Subpartner)
- Network Rail (Observer)
- FirstGroup plc (Observer)

4. Key Outputs

Key project outputs are:

4.1 A Sustainability Assessment Tool.

The aim is for the Tool to inform station designs, new build & retrofit projects and ongoing operation, leading to more sustainable solutions. The Tool is planned for a life beyond the SusStation project. More information follows in Section 5.1.

4.2 Demonstration Schemes

The SusStation demonstration schemes aim to inform the tool, prove the concept and, with over 170m station users each year, to achieve widespread public exposure. They are:

1. Accrington EcoStation - a world first low carbon station, offering a comprehensive range of low carbon passive design, renewable energies, local, recycled & low embodied energy building materials and community use/involvement. It is a medium sized station, with annual use of around 320,000 passengers. It has an A rated Energy Performance Certificate and an “Excellent” BREEAM rating. It opened in October 2011, since when it has won awards, from:
- Royal Institute of Chartered Surveyors North West Region - winner Sustainability Prize
- Royal Institute of Chartered Surveyors UK - runner up Sustainability Prize
- Network Rail Partnership Award - winner Environmental Sustainability.
- UK Rail Innovation Awards - winner Environment.
- Royal Town Planning Institute North West region - winner Sustainability.

See Figure 2 below.

Figure 2 Accrington EcoStation

2. Utrecht Centraal Renewable Energy Scheme. With PV and Aquifer Thermal Energy Systems for renewable electricity and heating/cooling. Projections show that energy for cooling, during the warmer summer months, is likely to be a key demand on the ATES. The PV panels, which are integrated (using cold bent glass) into platform canopies, are shown below in Figure 3. Completion of the final canopy is on track for completion in mid 2012. The aim is to produce 85,000kWh (equivalent to around 25 domestic properties) and meet 30% of the station's demand for electricity.

Figure 3 Utrecht Centraal Photo Voltaic panels within platform canopies

3. Station Green Modular EcoStation, Horrem, near Cologne. A low carbon station, intended as the first as a series of modular buildings across Germany. Infrastructure owner DB (Deutsche Bahn) sees that sustainability and passenger comfort are equally important for this project. The German regulatory baseline energy consumption figure (188kWh/m2 area per year[1]) will be compared with Station Green. Easy maintenance and reduced reliance on mechanical systems are priorities for sustainable operation. See Figure 4 below, which indicates the passive design and a green/PV panelled roof.

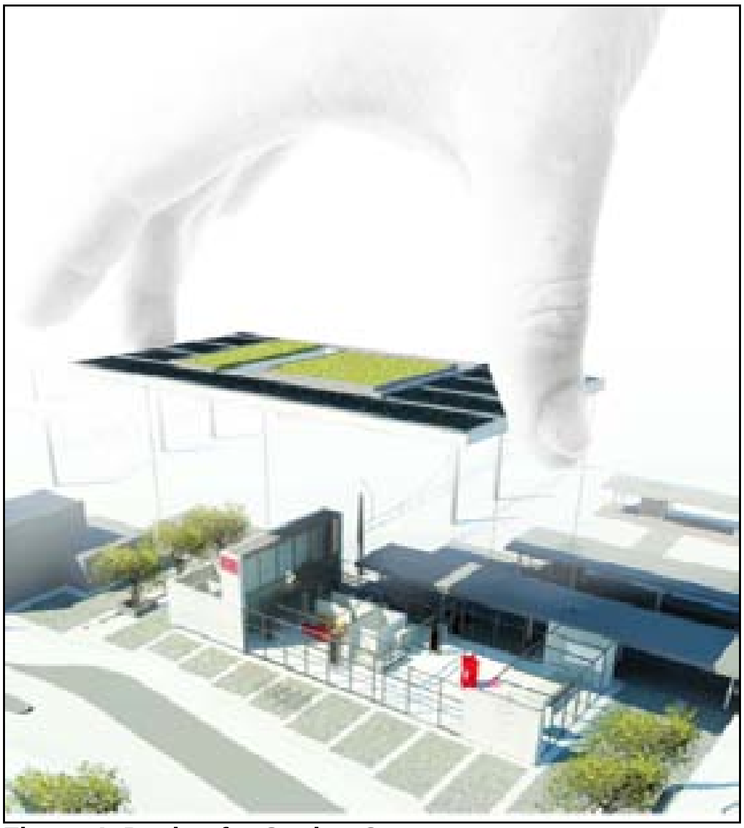


Figure 4: Design for Station Green

4. Antrim Bus & Rail Centre. Energy efficient refurbishment and extension of a historically recognised station building. This aims to integrate old and new structures, and achieve a higher quality customer offer as well as energy efficiency. The energy target is for a 15% reduction compared to current building regulations. The scheme begins in 2012. Plans are shown at Figure 5 below.

Figure 5: Antrim Bus & Rail Station Refurbishment & Extension

5. Design for Boulogne Eco-Quartier Gare. Plans for a sustainable (and highly accessible) redevelopment focussed on the station, supporting other spatial transformational schemes for the town. See Figures 6a and 6b below.

Figure 6a: "before" image of Boulogne Ville station area

Figure 6b: "after" architect's image of Boulogne Ville station area

5. Project Development Process.

In support of these outputs and the wider objectives, the partners & stakeholders are working together in the following areas:

5.1 Sustainable Stations Assessment Tool development.

Building on an early prototype for ProRail, the partners have overseen improvements to the tool and piloted its application across large, medium and small stations across North West Europe.

The tool is now available online, at www.sustainablestation.eu It is suitable for assessing existing stations (most useful for stations with buildings), for station improvement plans and for ongoing maintenance. The tool itself is supported by a manual (English and Dutch now, French and German versions are planned) available online. Future plans, for a secure and robust life beyond the SusStations project, are for a quality management system (QMS) and a user group. The tool has been trialled for use in the Netherlands, the UK and Germany. A French trial is planned.

The input process requires an onsite survey/design review supported by information about utility bills, gross floor area and passenger numbers. For an existing medium sized station (500,000 passengers/year) a half day survey involving two station property managers/similar professional would be required. The online version of the tool makes for easy collaboration, and will offer benchmarking opportunities. Other than for "Energy" subjectivity is an inevitable aspect of the process. The user manual and future QMS take this on board.

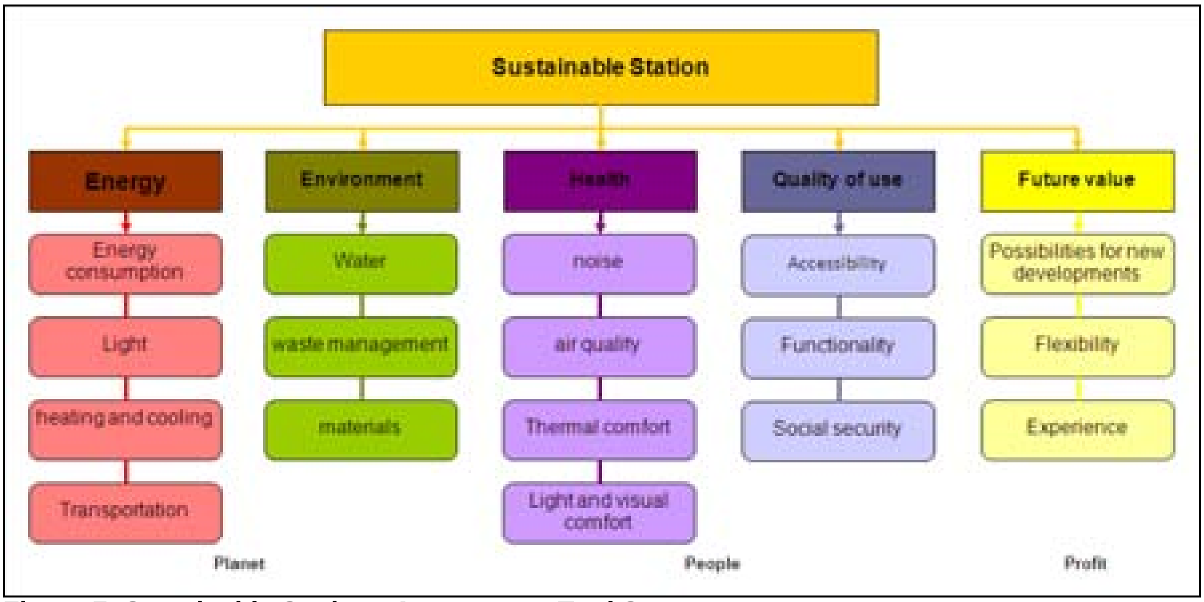


Figure 7: Sustainable Stations Assessment Tool Structure

<u>The tool's main outputs</u> are:

1. A sustainability score, overall and for each of the 5 themes (Energy, Environment etc. as in Figure 7 above). The scores are related to Dutch legislation valid in 2009, ProRail/NS Poort regulations and, if nothing exists, current construction practices.
2. Comparison of different variants, where required for alternative design schemes
3. Recommendations for sustainability improvements. For an existing station, recommendations are typically about modernising lighting, improving handling of waste, water saving on toilets and taps and improving the accessibility of the station for people who are less mobile.

<u>Application & Role of the Tool</u>

The Tool does not provide a detailed building assessment (as for BREEAM). It is however specifically aimed at rail stations, hence the importance of "quality of use", from planning of high level objectives through to maintenance. The tool is at an early stage. However, the train operators, infrastructure owners and governmental bodies involved in the project see its role in achieving more sustainable management, monitoring & development of their station assets.

As more stations are assessed and recorded on-line, the intention is that there should be opportunities for developing a database resource. Opportunities for benchmarking and for good practice examples could be particularly helpful for a rail industry keen to demonstrate its sustainability credentials.

It would be interesting to compare experience of sustainability tools for other building types.

5.2 Sharing good design and management practice

Good practice can be inspired by site visits and the project investments, learning from best practice – and from less good experience – from across the partnership and "friendly" projects. We have held workshops on defining the scope of a sustainable station, renewable energy, the new and retrofit scheme designs and working with schools. We have looked at the different incentives, and levels of uptake, for example, across the Member States involved in the project for PV systems. Information is available at the project website: **www.susstations.org/**

Sharing good practice will continue until the conclusion of the project in 2013. At this stage, our overall findings are as follows.

Lessons from Success:

- The earlier sustainability is integrated into the process the higher the result
- Invite a vision from the architect; don't stifle creativity/expertise from over-prescriptive specifications
- The client needs a vision of sustainability
- The value of involving local communities (UK is good practice)
- Setting targets not measures results in optimal solutions
- Use of local materials

Areas for Improvement:

- Involving the contractor at an early stage (the creative relationship between architect and contractor leads to optimal delivery). However, this may not be readily achieved through typical procurement processes.
- Technological solutions may vary by region (eg climate, rainfall …)
- Disseminating findings. Sharing them more transnationally, raising awareness
- Recognition of strong partnerships with sustainability on the agenda
- Flexible "future proof" interiors.

Areas for Further Research:

- Integrating whole life costs in investment processes. Misalignment between beneficiaries and investors is often a disincentive.
- Score non-economic values to influence decision makers (nb Triodos & some other NL banks are interested in monetarising social/environmental impacts of their investments and property agents are interested in how to market "green" buildings).
- Portfolio of good practice examples, available via the web-based Tool.

5.3 Sharing monitoring & findings.

All schemes will be monitored. Just 1 scheme however has been opened to date – the Accrington EcoStation. Findings for this scheme are available through:

1. a Design Report[2] including lessons learned prepared by scheme architects Strzala Bright Seed. One of the issues raised in this report related to difficulties with using reclaimed materials e.g. additional time on site to clean up locally reclaimed stone. Ensuring traceability of material origin, in line with the local materials design ethos, was also problematic. This is compounded when amounts required are relatively small. There were also some improvements and alternative options concerned with the contractor. Accrington was procured through a "Design & Build" contact, which is helpful in giving the client protection from delivery risk. At the tender interview stage it is important to ensure special requirements such as working with reclaimed materials have been adequately allowed for by the contractor. The architect suggests that Design & Build contracts tend to be prescriptive; a partnering contract may allow for achieving optimal outcomes.

2. an Intelligent Building Management system intended to monitor ongoing energy and water use. There have been insuperable problems with this system, however, so that monitoring data is not yet available. This is disappointing. By reference to meters within the former and new buildings, it has been possible to present some data on energy use, set out in Table 1 below. The former station building dated from the 1970s, and while unattractive to passengers was a typical brick built structure for its time. It was demolished with materials reused locally after opening of the EcoStation. The energy use data includes some additional use during the construction phase, so are probably slight overestimates. All figures relate to consumption per year, with data available after completion in August 2010 i.e. covering 2 winters, again, leading to an overestimate of use.

The principle finding from Table 1 below is that the new EcoStation uses less than half the energy (measured per m^2 of floor area) of the former building. Current figures suggest around 34% of electricity demand, or 13% of total energy demand in the EcoStation building, is met from locally generated renewable sources. With a longer monitoring period, including a fairer proportion of winter and summer months, both energy efficiency and renewable energy figures are likely to improve further. This will be reported on by the project.

Table 1: Energy consumption data for Accrington EcoStation

	Former Station	New Station as projected by design team	Actual
Electricity consumption - total	n/a	27,348 kWh	23,815 kWh (1)
Electricity consumption - car park	n/a	1,500 kWh (2)	Assumed as projected
Electricity consumption - building	17,000 kWh (3)	25,848 kWh	22,315 kWh
Greenhouse gas emissions associated with the building's electricity consumption (4)	8900 Kg CO_2 equivalent		
Electricity consumption per m^2 building floor area	570 kWh/m2	112 kWh/m^2	97 kWh/m^2
Electricity generated by PV	0	6719 kWh	7500 kWh (4)
Renewable electricity as % of total used in building	0	26%	34%
Gas consumption	0	31,500 kWh	37,000kWh (5)
Gas consumption per floor area	0	136 kWh/m^2	160 kWh/m^2
Total energy consumed in the building	17,000 kWh	58,800 kWh	59,000 kWh
Energy consumption per m2 building floor area	565 kWh/m^2	255 kWh/m^2	255 kWh/m^2
Typical UK energy consumption per m^2 domestic building	453 kWh/m^2 (6)		
DB baseline energy consumption per m^2	188 kWh/m^2 (7)		

Sources:
(1) Meter reading on 25 Jan 2012, encompassing 18 months (2 winters) of station operation, showing 32,802 kWh, plus 2922 kWh electricity generated and used on site (excluding electricity generated on site and exported to the grid).
(2) Author's calculations – 12 no lighting columns, each of 70W, in use until after last train (midnight) 5 hours per average day, 365 days per year.
(3) As supplied by design team.
(4) Data sourced from system inverters on 25 January 2012, data extrapolated for most recent system which became operational in October 2011.
(5) Meter reading on 26 Jan 2012, encompassing 18 months (2 winters)
(6) http://www.communities.gov.uk/documents/planningandbuilding/pdf/319282.pdf
(7) Presentation from Deutsche Bahn dated June 2011

More detailed consideration of energy consumption at the station is as follows.

Projected energy consumption levels were for lower electricity use and higher gas use than actual levels (combined, very close to actual). We are not sure why there is a difference – higher gas consumption could be because of increased use of the basement building (for community rail activities) than planned.

Electricity is used at the EcoStation for lighting and passenger/ticket retail systems. Gas is used for space and water heating. The former station was, by contrast, powered entirely using electricity. The new station's passive design is intended to maximise natural light, temperature control and ventilation, with full details set out in the Design Report as above. Nonetheless, energy from gas for space and water heating is the heaviest use of energy, as shown in Table 1 above.

UK public health requirements (to avoid Legionnaire's Disease) have dictated that the hot water temperature (used in the public and staff toilets) is kept at 60^{o}C during opening hours. The latest advice is that periodic boosting to this temperature may be sufficient to meet public health requirements and require less energy. This option will be further investigated. It is likely, however, in line with general building trends, that space heating is the predominant demand for gas in the building.

A ground source heat pump was investigated by the design team, as a renewable option for space heating. The relatively small load at the station, combined with the system cost, meant that this option was discounted.

For all national rail networks involved in this project (UK, France, Netherlands and Germany) public space at stations are not normally heated or cooled – heating is required only for staff and commercial areas, where they exist.

Electricity for lighting and passenger information systems on the two station platforms are (following the divide in property responsibilities in the UK) the responsibility of Network Rail, the national infrastructure owner. Typical demand at Accrington can only be estimated from a quarterly bill (which may be based on estimated rather than actual figures), which indicates around 30,000 kWh for these functions per year.

For renewable energy, there are PV systems installed in 3 phases – October 2010 (12 arrays on car park lighting columns) and on the station roof, dating from February 2011 (14 arrays) and August 2011 (13 arrays). Because some of the systems are only recently installed, generation levels will be reviewed and updated over the next year or so. The most recent systems, located on the roof, seem to be generating most efficiently, suggesting that the technology is progressing. Electricity meters indicate that over half of this renewable electricity (around 58%) is exported to the national grid, with the remainder used on site. There is also a solar thermal system for helping heat hot water. No additional space is available for further expansion; current provision is the maximum possible.

3. The Station Travel Plan, which includes monitoring of access to the station by mode, intended to encourage more sustainable modes of travel.

To encourage good access to the station, and access by sustainable modes of travel, passengers have been surveyed and marketing and information campaigns undertaken. Infact, walking, one of the most environmentally benign modes of transport, is already the most important way of getting to the station (see Table 2 below). This probably reflects the station's town centre location. The 40 space station car park tends to be full by mid-morning. Cycling is relatively insignificant, possibly because of the hilly nature of the town, but is somewhat disappointing, given that good facilities and access are provided. Overall, however, access to Accrington station is predominantly by sustainable, low carbon modes.

Table 2: Mode of Access to Accrington EcoStation & Carbon Dioxide Emissions by Mode

Main Access Mode	**June 2010 (1)**	**March 2011 (1)**	**Emissions per passenger km (2)**
Walk	62%	59%	
Cycle	2%	1%	
Car – parked at or near station	7%	7%	208 g CO_2 (3)
Car – dropped off	12%	12%	208 g CO_2 (3)
Train (changing trains)	1%	2%	57 g CO_2
Taxi	6%	9%	215 g CO_2
Bus	10%	10%	160 g CO_2
Other	0%	0%	
Total	100%	100%	

Sources:
(1) Eden Business Analysis *Accrington Eco Rail Station Research Report* May 2011

(2) UK Department for Environment, Food and Rural Affairs *2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors* October 2010
Note:
(3) Figure is per vehicle km, not passenger km

4. User surveys, revealing how local people perceive the station.

Both attitude and footfall monitoring surveys were taken, before and after opening of the new Accrington station[3]. The main conclusions are:

- an additional 10% growth in passenger use of the station was due to opening of the new station[4]. The analysis used out 2 different models, which made allowance for external factors i.e. general growth on the corridor, and came to this conclusion. It would be difficult to accredit the sustainable design contributing to this overall impact – the passenger would be aware of the general improved environment. This substantiates the point of view that passenger comfort should be considered alongside sustainability issues. Aesthetically, use of local stone makes the station complementary to other attractive town centre buildings, which is part of the sustainable design ethos. Passenger comments (see below) also suggest good awareness of sustainable design. Additional growth of this order is a substantial revenue impact. It is also good for achieving sustainable, low carbon travel. The UK official transport appraisal model[5] suggests that 26% of growth in rail passenger km represents a direct shift away from the car.
  The analysis of passenger growth was carried out with 6 months of data after opening of the station; the full effects of the new station will be reached for up to 2-3 years later, as people change their travel behaviour. It is reasonable to expect future growth above 10% due to the new station and this will be monitored and reported by the project.
- more people bought tickets at the station (compared to on the train or elsewhere) following opening of the new eco-station, even though opening hours were unchanged. The conclusion is that revenue protection (a major issue for the rail industry) is improved.
- 92% of passengers were "satisfied" or "very satisfied" with how easy it is to access the station (an improvement compared to before opening)
- Satisfaction with all specific aspects of the station improved – including most of all for "ticket purchase facilities" and for "overall appearance"
- Typical user comments on the station: "nice, modern, new, smart, lovely, stylish, fresh, attractive, welcoming". There were also comments on "How well the building sits with the surroundings" "fantastic - very impressed" and "I like the environmental credentials".

Moving to other experience from across the project, and comparing stations to other building types. Issues highlighted by experience from the project are:
- The importance of <u>comfort</u> for passengers alongside <u>sustainability</u>. Sustainable design must not be at the expense of passenger comfort (and thereby passengers changing from rail to car). The role of stations in a sustainable & integrated transport network is a defining characteristic.
- Experience from Station Green, the Berlin Hofbahnhof and Dutch stations confirms that only a proportion of energy can be generated from PV systems. This probably differentiates stations from other types of building for which nearly/zero carbon status seems to be achievable.
- Wind power is not generally appropriate for stations, typically located in busy urban environments
- Geo-thermal renewable energy schemes can be appropriate for space heating in the largest city centre stations, but, as for all building types these will typically be large scale installations and will depend on local ground conditions.
- Sustainable buildings are more expensive – by an estimated 25% for Station Green compared to the conventional option. Returning to the Accrington experience, the architect suggests that the additional cost is particularly dependent on the extent of renewable energy systems incorporated. It would be interesting to have some comparative experience of costs for other building sectors.

5.4 Working with Local Communities

ProRail, Lancashire CC and Translink are particularly active in working with school children from age 9 to 16, partly inspired by the project. Accrington, for example, offers activities and space for local schools' environmental projects within the building, see Figure 8 below, supported by a new DVD targeted on children aged 8-11.

Figure 8: School children at Accrington EcoStation

Space is also available at the station for an allotment. This has been adopted by the Prospects Foundation, a local mental health charity, for growing vegetables. See Figure 9 below.

Figure 9: Community food growing initiative

Translink has long standing programmes of working with local community groups in Northern Ireland. As part of the Antrim scheme, the project manager has visited all local primary schools. A competition was launched in January 2012 for local school children to design the site hoarding, now that construction is about to start. Local school children accompanied the Northern Ireland Transport Minister, Danny Kennedy, at the scheme launch in December 2011, shown in Figure 10 below.

Figure 10: Launch of Antrim Integrated Bus & Rail Centre scheme, with (from left to right, background to foreground) Helen Donaldson, of the EU Special Programmes Body, Danny Kennedy, the Northern Ireland Transport Minister, Catherine Mason, Chief Executive of Translink, and local primary school children.

Working with local communities can support social empowerment and cohesion. It can also achieve a sense of local ownership of the station. This in turn helps improve security, reduce vandalism in station areas and help to increase rail use. Many school children in Accrington, for example, come from families who don't tend to travel much at all, and wouldn't otherwise have thought of using the train. For these reasons, the UK Government has developed a Community Rail Strategy to foster these initiatives.

5.5 Working with Professional Target Groups

Our professional target groups are the rail industry & the built environment sectors (alongside the Envireo "cluster" of projects also involved in low carbon buildings) – to promote the sustainable stations concept. For this reason, the project is represented at IEECB 2012!

Comments from interested parties are welcome, and most project events are open.

For more information about Envireo, which includes historic renovation of buildings, life cycle methodology and industrial buildings, the website is at: www.envireo.eu/

6. Outcomes & Impacts

This project is very much a "work in progress", with preliminary impacts as above. We would be delighted to update interested parties in due course. With the conclusion of the project in December 2013, we look forward to:

1. Our demonstration buildings and schemes, accessible to the public across North West Europe. These demonstrate:
    a. Potential for significant energy saving
    b. Potential for increased use of renewable energy
    c. As part of a holistic approach which values passenger comfort alongside other sustainability improvements, potential for increased use of rail, as a low carbon and more sustainable mode of transport, and as part of this, a shift from car to rail
    d. Potential for sustainable building improvements to catalyse local community engagement
2. The assessment tool, with positive indications to date for take-up across the rail industry
3. Greater awareness and cultural acceptance of the value of sustainability improvements, particularly in the rail industry. Hand in hand with this, more awareness and acceptance of sharing information and best practice transnationally

The partners are also keen to see how life cycle costs can be integrated into investment decisions. This is a priority for future sustainability improvements.

As transport practitioners involved in the project, it is always good to see building schemes which are located, planned and managed so that people can access sustainable buildings without being car dependent.

This project has received European Regional Development Funding through INTERREG IVB.
nwe INTERREG IVB

[1] Source: Presentation (not in public circulation) by Deutsche Bahn dated June 2011

[2] Source: "Design Report – Accrington Eco Railway Station" prepared by SBS Architects published September 2010 and available at www.susstations.org/

[3] Source: "Accrington Eco Rail Station Research Report" prepared by Eden Business Analysis dated May 2011 and available online at www.susstations.org/

[4] Source: see 3 above.

[5] Source: http://www.dft.gov.uk/webtag/ as accessed on 27 January 2012

Flannery Centre: Low energy training building for a dry continental climate

P Bannister[1], P Taylor[1], C Ardren[1], A Bland[2]

[1]Exergy Australia Pty Ltd [2]Skillset

Abstract

The Flannery Centre is a new multiuse educational and office building located in Bathurst on the tablelands of New South Wales in Australia. It has been designed to make full use of the opportunities inherent in the regional climate through passive design features. This approach, in combination with appropriate technology and control, seeks to achieve an appropriate level of thermal comfort with low energy consumption. The design was developed and optimized through a process of iteration under a project-management led design team.

The building design includes the following features designed to minimize energy use: under-floor displacement air delivery system run from air handling units that have direct and indirect evaporative cooling, heat recovery wheels and desiccant wheels; natural ventilation for primary cooling in shoulder seasons; no refrigerative cooling (in spite of peak summer temperatures in excess of 35°C), re-circulation for efficient start up in winter and a large photovoltaic array and a small wind turbine.

This paper presents the design itself and the design process, the system selection and its control and descriptions of some of the obstacles encountered and overcome during the construction process.

Introduction and background

The Flannery Centre – named after the world renowned environmentalist and author Tim Flannery – is in its final stages of construction in Bathurst NSW (Figure 2). An architectural impression is shown in Figure 21 and a view of the almost completed building is shown in Figure 3 .

Figure 1: Flannery Centre – Artist impression – North elevation

Figure 2: Flannery Centre – Location in NSW, Australia

Figure 3: Flannery Centre – nearing completion December 2011

Skillset, (the owners of the new Flannery Centre) is a group apprenticeship and training company servicing much of regional NSW. Over the past few years senior management has become increasingly aware of and concerned about global issues including climate change, peak oil, food security, biodiversity decline, etc. A decision was made at Board level to build resilience against potential shocks, not only within Skillset, but throughout the Central West business community. They required an energy efficient building that would demonstrate to the community their concern about climate change as well as operating effectively under potentially changed climate conditions.

Skillset identified the need for a skills training centre that goes beyond the normal curriculum for trainees and apprentices. When a funding opportunity became available, the company made the decision to build a centre that would not only act as a place to better prepare clients, but would in itself be a flagship for sustainable and low carbon emission design.

This background is important because it illustrates that the personnel involved in driving the project have a genuine commitment to sustainability and are well informed of the issues. The project is not about ‘looking good’. The client is alert to ‘greenwash’ and is averse to compromising building performance. This unyielding commitment has had significant impact on the design and the construction team members – with some team members having to be replaced.

Project Objectives

The aim of The Flannery Centre is to educate in the principles of sustainability, whilst concurrently embodying and demonstrating those same principles.

Specifically the functional requirements and performance targets for the building are:

- Accommodate approximately 200 students/trainees in collaborative learning spaces
- Achieve thermal comfort standards as defined under ASHRAE 55 2004
- Ensure that all functional areas have a visual connection with the outdoor environment
- Be an example of a positive future in a carbon constrained economy
- As far as possible be self-sufficient in terms of water and energy, and use systems that ensure the maximum CO_2 emissions do not exceed 25kg/m²/annum

Design Concept

The design process commenced with a "discovery" of the educational and functional needs of the centre and the development of the required spatial layout (Figure 4).

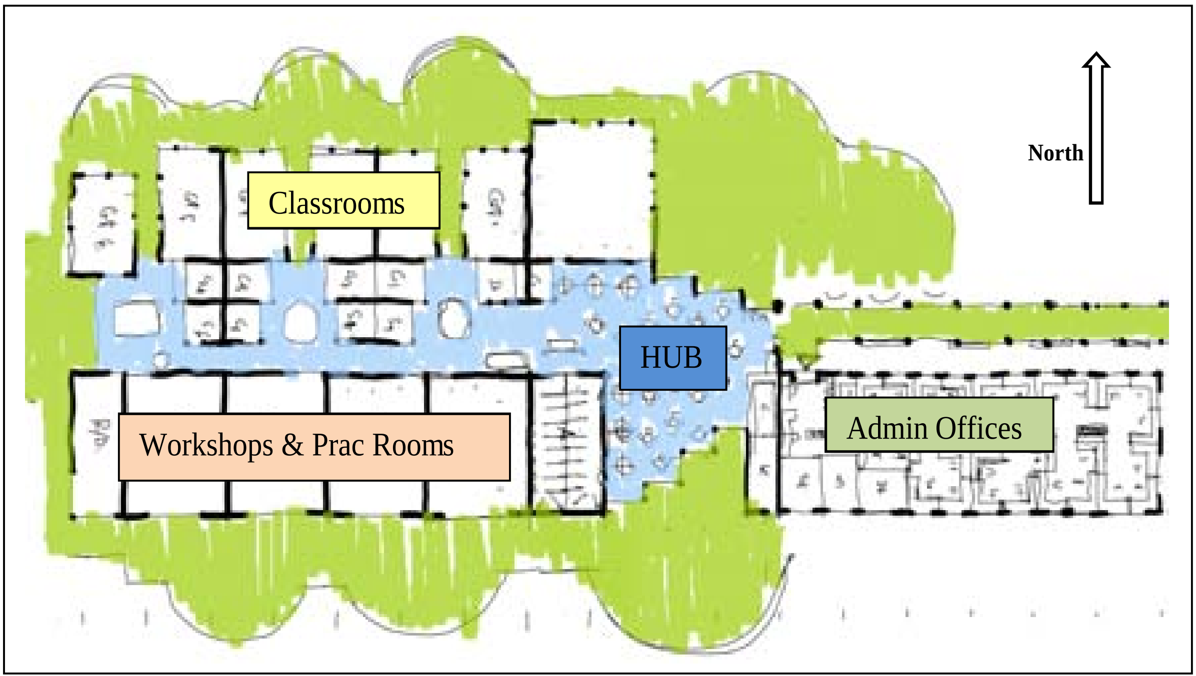


Figure 4: Flannery Centre – Spatial Concept layout

The vision for the Flannery Centre is for it to be recognized as the centre of excellence for business sustainability in the Central West region of NSW as well as carrying out its didactic function. With this in mind the team commenced preparing a design that would provide a venue suitable for colleagues, researchers and the community to come together in congenial surroundings to discuss, debate and explore sustainability issues that are pertinent to everyday business in the region. This called for the creation of an energised central "Hub" that would invite people in and provide the facilities and ambience that would encourage robust and creative problem solving.

In support of the "Hub" there was a call for a permanent space that would be available to demonstrate new and innovative technologies and work practices. This Gallery, located between the classrooms and the workshops, has been crafted in such a way that it is able to be adapted with minimal effort to operate as break-out spaces for group-learning using fold-out screen dividers which do not impact on the conditioning of the space (Figure 5).

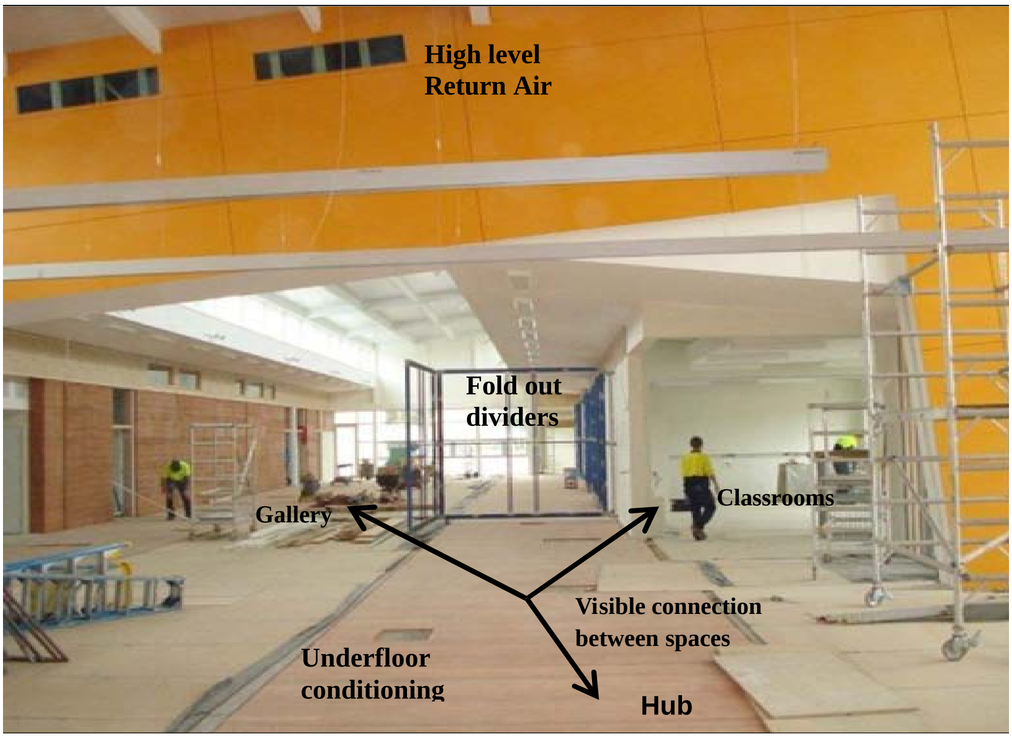


Figure 5: Flannery Centre – View from Hub into Gallery – Complete flexibility of space

The underlying functional relationships between the various parts of the Skillset business were also catered for in addition to the educational spatial requirements. The building is designed to allow for noisy and energetic interactions in the Hub area, tapering away to quiet personal places of study and contemplation in gallery and seminar rooms, while being surrounded with visible signs of learning and innovation.

These principles of functional layout and usage patterns have greatly assisted the design team in making decisions about how the facility is to be conditioned. It has called for providing quiet, unobtrusive and efficient conditioning in a manner that makes occupants feel that, while they are thermally comfortable, that they can still maintain a continued connection with the natural environment and outdoor climatic conditions. This has been achieved through the use of strategically placed (high and low level) double glazed windows, high thermal mass and super-insulated walls and roof.

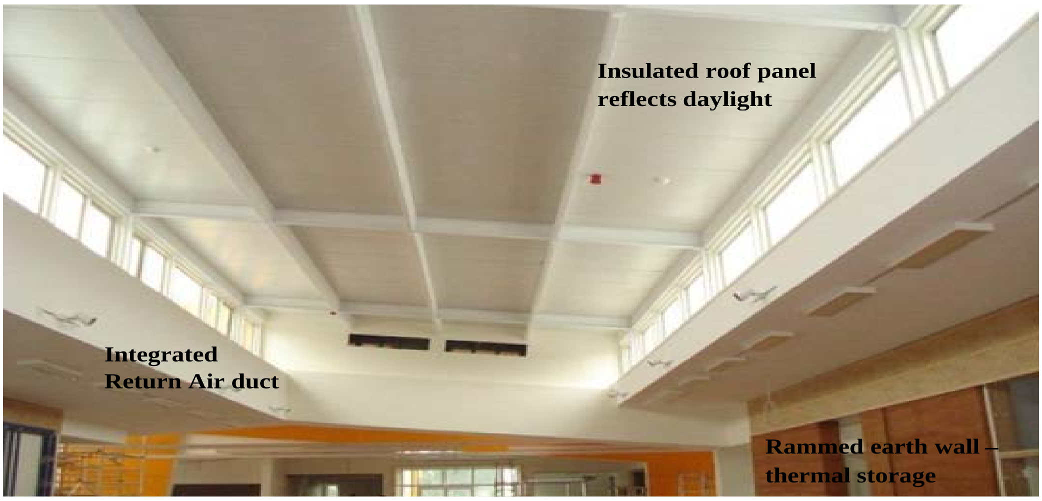


Figure 6: Flannery Centre – Gallery – Daylight, thermal mass and integrated ducting

The building users will enjoy the benefit of having direct outside views available from more than 75% of the building and with ideal daylight levels occurring across more than 90% of the floor area. They will also have access to natural ventilation with manually operable windows.

The building is already performing well and, since being sealed 6 months ago in September 2011, has maintained a comfortable working environment regardless of outside ambient conditions and with no mechanical systems operating. Indeed, anecdotal feedback from contractors is that the building is good to work on because it is always comfortable and light. Even though the design team was faced with a large number of hurdles to overcome in the design process, the final design and constructed building has been able to take full advantage of its passive design features and opportunities inherent in the regional climate.

Design process

Over the past three decades as Ecologically Sustainable Design (ESD) has gained popularity, there are numerous examples of projects that have successfully achieved their environmental outcomes, and equally, a large number more that have failed. Fortunately we have moved out of the era of guess work to a position where designs can be simulated and tested prior to committing to untried technologies and methods.

To consistently produce sound ESD buildings, one needs to implement systems and processes that are rigorous and scientifically based.

The process required for a successful and innovative ESD design needs to allow for multiple iterations, reviews and prioritisations, always keeping in focus the core elements of the design:

- Space and Functional use (fit for planned use)
- Cost
- Environmental and energy performance
- Thermal comfort

With each iteration, the design team needs to bring in the next couple of elements (importance of each element is dependent on project objectives), update the design and verify that the core elements have not been compromised unwittingly. This process is shown in Figure 7.

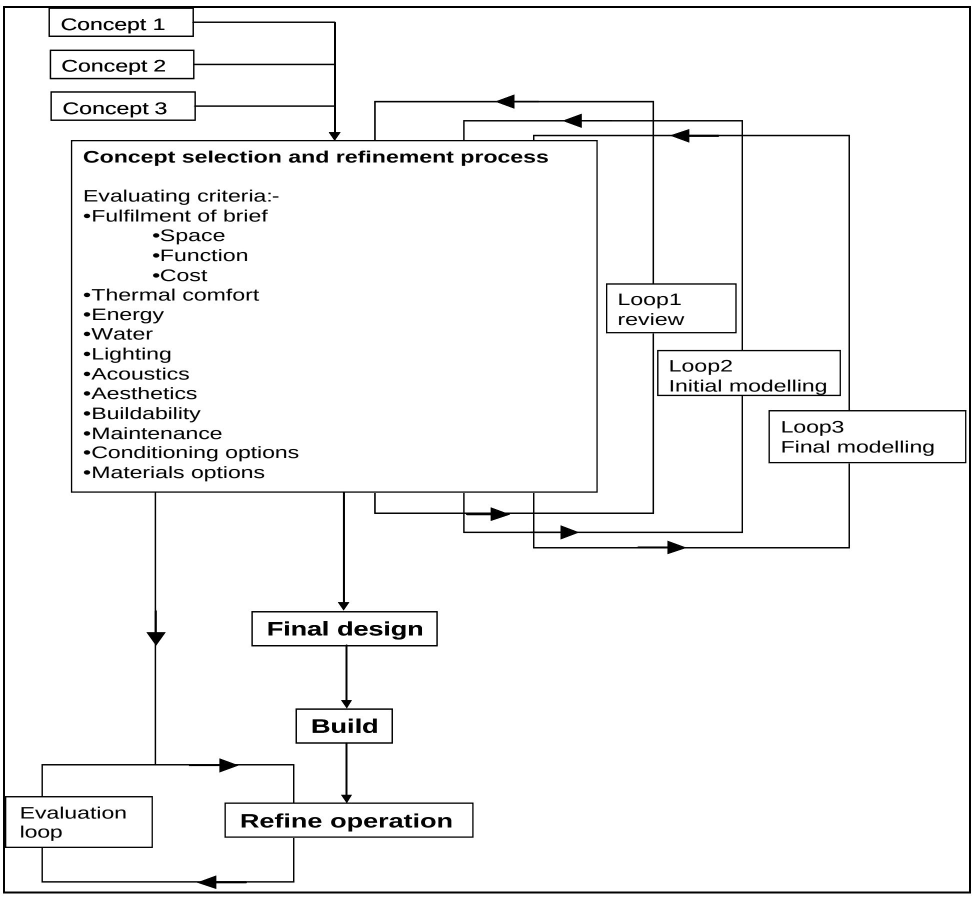


Figure 7: Flannery Centre – Iterative design process diagram

The majority of design teams today make the mistake of going “straight to the solution” that has been used on the previous project. This approach is fraught with danger as “old problems” are repeated and perpetuated.

A crucial requirement for success of the above process is the “continuity of intent” through all stages of planning, design, construction and commissioning. While this would seem to be obvious, many have shown how the “we always do it that way” approach takes over whenever the project is under pressure. This occurred in the Flannery Centre design process when the design engineer simply removed key efficiency items of scope when under pressure of time and cost.

Our experience has shown that the “continuity of intent” is best enforced by using a “project management driven” design team.

Selection of Conditioning System

Before the current evaporative displacement system was chosen, the design team worked through the a number of alternatives (**Table 1**) before identifying the most appropriate fit in terms of energy efficiency, thermal comfort, cost, functional use of highly flexible zones and aesthetics.

An important consideration in the selection of the conditioning system lay in the highly transient usage pattern of the teaching and learning spaces, going from full occupation and excess heat loads for short periods of time, to long periods of low or no occupancy.

This usage pattern is not mirrored in the office spaces and these areas therefore are serviced with their own dedicated conditioning plant to best respond to the largely “static” load.

Figure 8: Flannery Centre – Gallery and Hub with timber floor plenum [L] and PV array [R]

Selection of Conditioning System

The table below lays out a few of the systems investigated with the benefits, disadvantages and reasons for rejection or retention.

Table 1: Flannery Centre – Selection of conditioning system alternatives

No	Description of proposed System/technology	Advantages	Disadvantages	Reason for rejection
1	Refrigerative VRV	– Proven technology, – responsive to transient usage pattern, – high degree of user control – cost effective	– would not maximise use of ambient climatic conditions – refrigerative fluids have poor environmental credentials	Skillset rejected this option based on isolation of thermal conditions from outside ambient conditions. It would not maximise the benefit to be gained from "active passive" design elements of the Flannery Centre. Loss of learning opportunities for occupants/visitors
2	Geo-thermal heating/cooling (vertical)	– "new" technology for Bathurst region, – Make use of passive renewable energy, – Leverage static ground temperature	– Costly – Not responsive enough for transient load – Poor soil conditions and conductivity	This option was rejected on the basis of cost and the modelling showing that soil conditions were not ideal.
3	Geo-thermal heating/cooling (horizontal)	– "new" technology and approach for Bathurst region, – Make use of passive evaporative cooling in wetland	– Costly / extensive pipe lengths – Poor soil conditions and water permeability – Not responsive to transient load	Required pipe lengths were found to be in excess of 1000m for reasonable contribution. Excessive embodied energy required High cost of installation and high impact on local environment
4	Direct evaporative cooling	– Proven technology in regional Australia, – Cost effective – Works well with ambient conditions	– High levels of humidity – Ineffective in high volume spaces	Simulation showed that thermal comfort levels would not be achieved for significant periods Excessive highly visible ductwork Little or no learning/demonstration
5	Two stage evaporative displacement system with desiccant drying	– Maximum flexibility – Works together with ambient conditions – Humidity control – Conditions the "habited zone" only – "new" technology in regional Australia	– Requires management of stratification with large volumes of low pressure air – Underfloor plenums are costly – Limited availability of desiccant units	Low pressure displacement system provides responsive, yet targeted cooling/heating Maximises flexibility of high volume spaces and office spaces with unknown growth Works well with passive design features Provides learning/demonstration Eliminates unsightly ductwork resulting in future-proof "clean-line" aesthetics

HVAC Design Philosophy

The Flannery Centre is designed as a showcase low energy building using practical technologies that are well adapted to the local climate. In targeting these goals, it was identified that special consideration needed to be given to the following features of the building and its location:

1. The building primarily consists of teaching spaces which alternate between periods of limited use and period of intensive use with high outside air demand.
2. The climate in Bathurst is cool by Australian inland standards, with mild summers and limited cooling requirements (Design cooling dry bulb temperature is 35°C) and cold winters.
3. The climate is dry (Design cooling wet bulb temperature is 21.5°C), indicating that methods of cooling that make use of wet-bulb depression will be most effective.
4. The climate has large diurnal temperature swings,

The following two figures show key weather statistics illustrating the above points relating to climate.

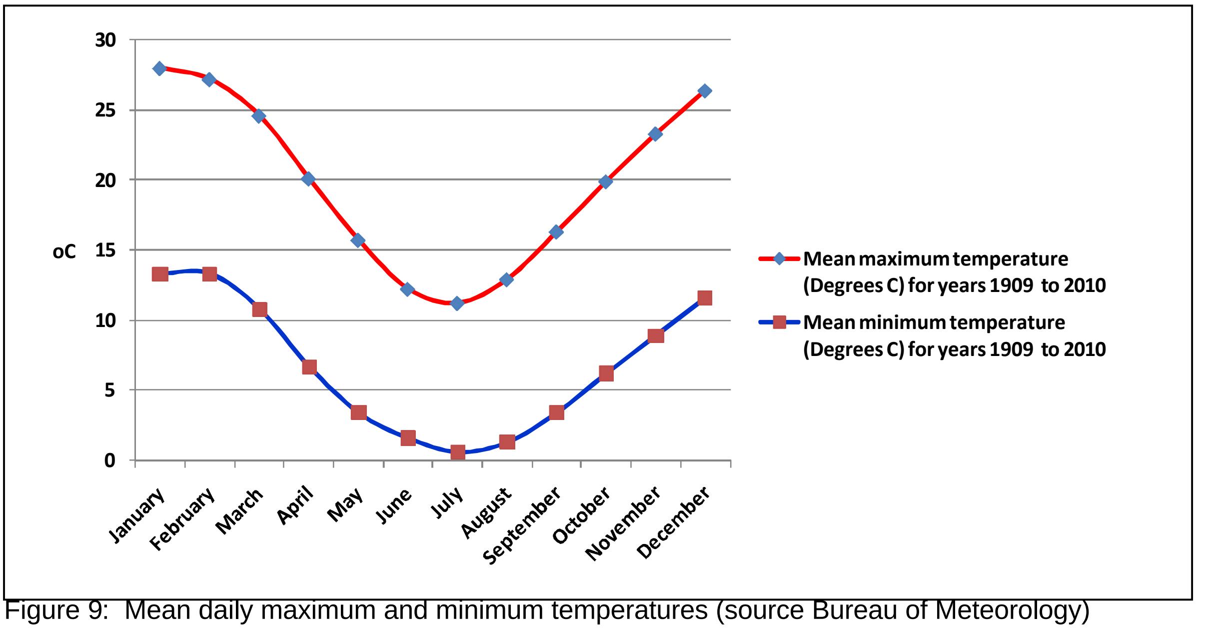


Figure 9: Mean daily maximum and minimum temperatures (source Bureau of Meteorology)

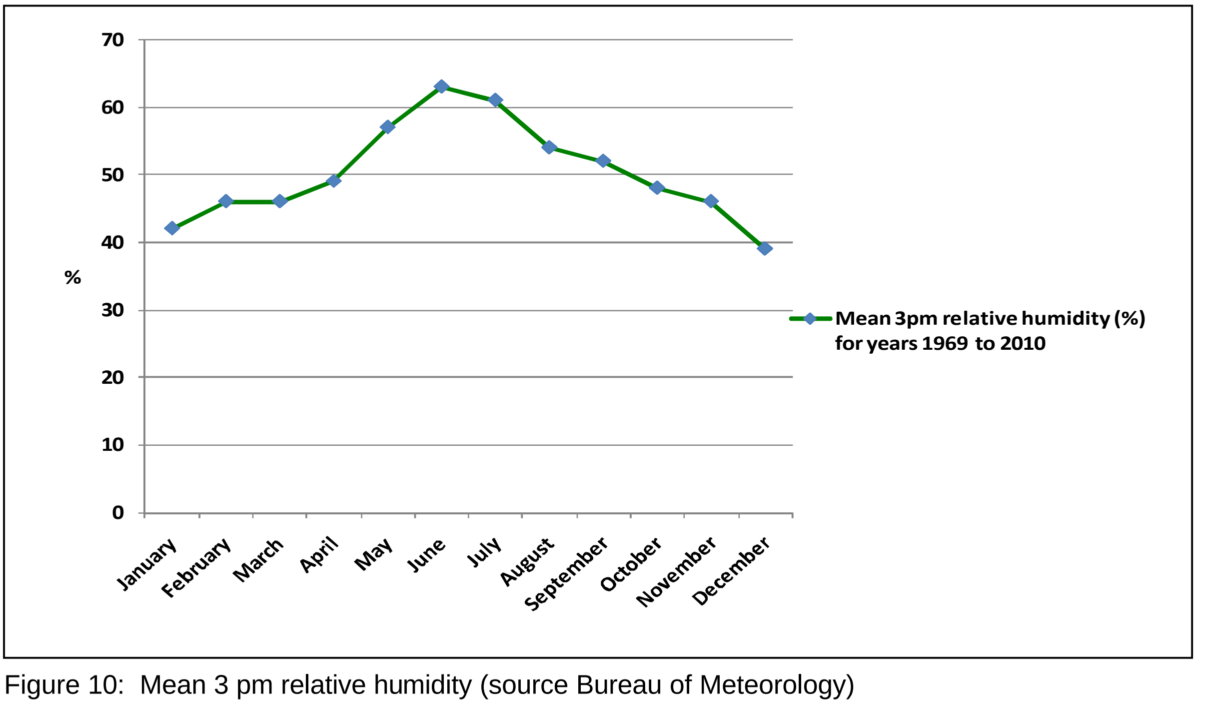


Figure 10: Mean 3 pm relative humidity (source Bureau of Meteorology)

On the basis of the above characteristics, the following decisions were made:

- The primary focus of the design is on the efficient treatment and management of the outside air. Indeed it was identified via simulation that the outside air load comprised as much as 80% of the total heating load and 33% of the cooling load.
- In winter, the rooms are heating driven and benefit from solar gain input, while in summer solar gain is undesirable. However glare is problematic at all times. As a result the windows are provided with moveable external shades for sun blocking and internal blinds for visual comfort control.
- An underfloor displacement system with variable volume control was selected for the site, utilising a two stage evaporative cooler with heat recovery for cooling. This system is capable of providing 19°C supply air on a design day in Bathurst without refrigerative cooling. As a result it is ideal as a solution to the provision of cooling – and recovery of energy during heating - of high volumes of outside air in this environment.
- The building has allowance for the use of natural ventilation overnight via manually opening windows at low level and high level mechanised window openings.
- The building is – by Australian standards, at least - hyper insulated. The roof is constructed of insulated sandwich panels (R= 5.2 m^2K/W). Walls are insulated with an R-value = 3.5 m^2K/W.
- High performance windows are used, with SHGC=0.62 and U=1.9 W/m^2K. The windows are double glazed clear glass to achieve maximum daylighting. The low-e coating is on surface 3 (outside of inner pane) for the purpose of keeping heat inside the building during winter.
- Heating hot water is generated using a condensing boiler circulating on 50/30°C basis to heating coils at AHUs and zones.

As the building nears completion, we installed a series of temperature data loggers to track the response to outside air temperature variation during summer and early autumn. The results have shown that in all areas except those subject to direct western solar gains, that the indoor temperature is reasonably stable.

The summer plots show, that while the outside air temperature fluctuated across a range of almost 20^{o}C, the indoor room temperatures fluctuated by no more than 6^{o}C. (Figure 11)

The autumn (cooler) period shows, except for the logger placed on an un-shaded western window exposed to direct sunlight, all indoor temperatures had a maximum fluctuation of 5^{o}C (19-24^{o}C). In the same period, outside air temperatures fluctuated by 17^{o}C, ranging from 9^{o}C to 26^{o}C. (Figure 12)

These plots serve to indicate that as an unconditioned space, the combination of building envelope construction, thermal mass and super insulation, has produced a building that is able to hold a stable and comfortable indoor temperature. This would indicate that the mechanical conditioning system is only really required for the removal of introduced loads of occupants and equipment.

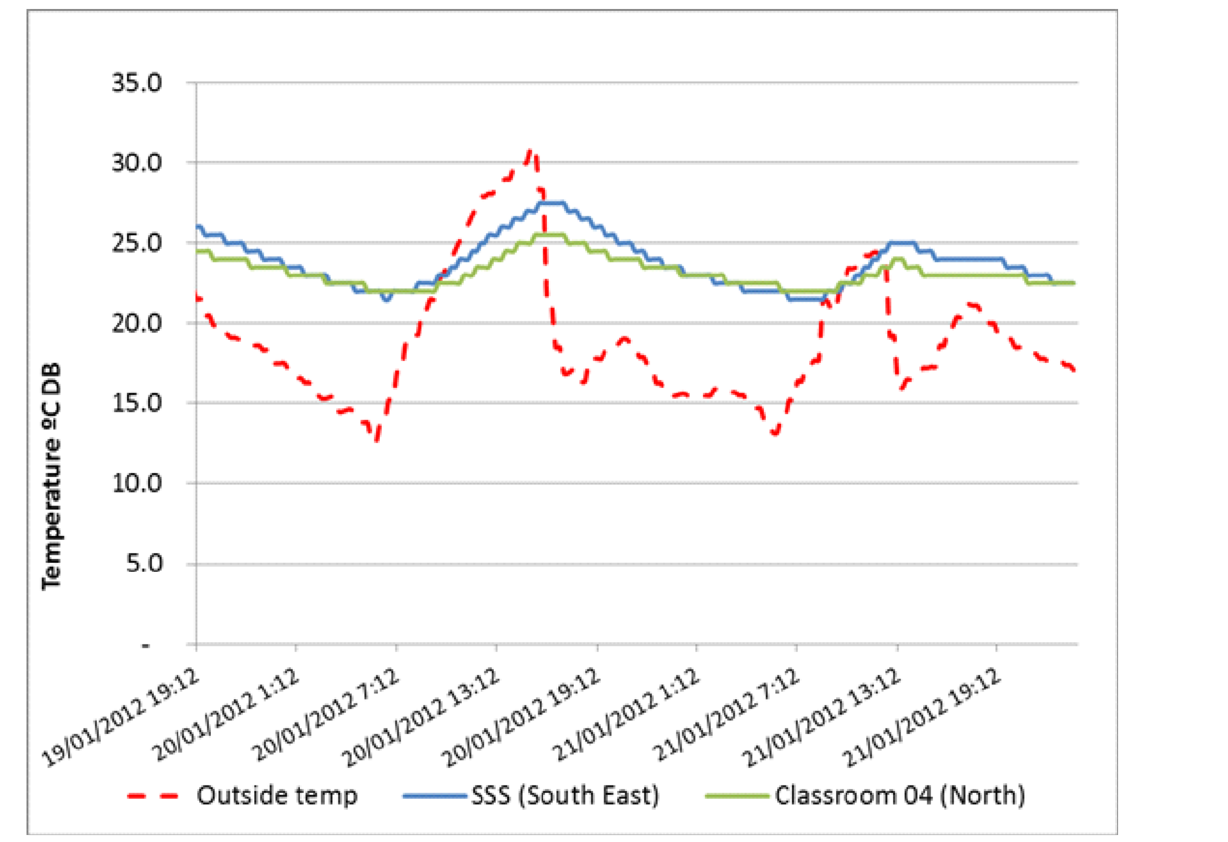


Figure 11: Indoor/outside temperature – Summer

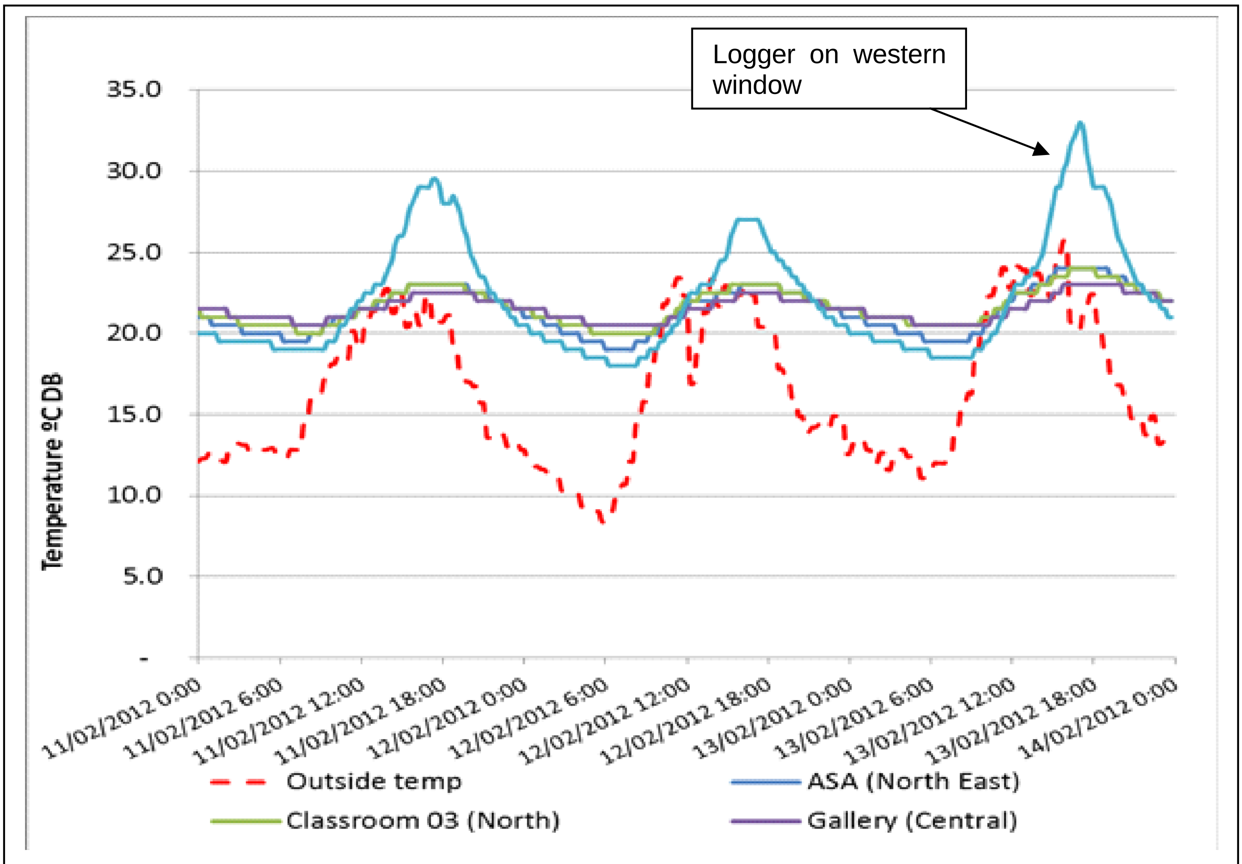


Figure 12: Indoor/outside temperature – Autumn

System Details

Two Stage Evaporative cooling with Heat recovery

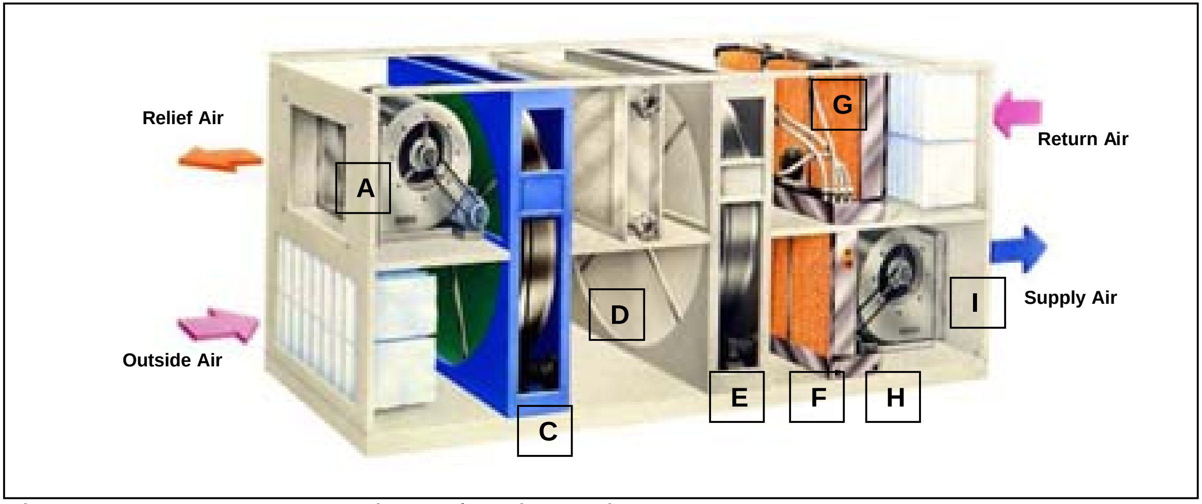


Figure 13: Two stage evaporative cooler – isometric

The evaporative coolers are central to the design philosophy of this building. The coolers work by providing both direct and indirect evaporative cooling to the airstream to achieve the required design minimum supply air temperature of 19°C.

Referring to **Error! Reference source not found.**3 and 14, the cooler works as follows:

1. Outside air is drawn into the unit and if desired mixed with relief air from chamber A to form the basis of the supply air.
2. The outside air is drawn through optional desiccant wheel C, reducing the air dewpoint. Note that at this stage the desiccant wheel has not been included in the design but provision for later addition is being made.
3. The supply air is then passed through the rotary heat wheel E, exchanging heat with the relief air (which may be evaporatively cooled at this point, providing indirect evaporative cooling to the supply airflow).
4. If the supply air is still too cold, it can be heated via heating coil F.
5. In summer, direct evaporative cooling can be provided in chamber H
6. The air is then circulated to the building via supply fan I
7. Return air from the building is drawn into the air handler and if required evaporatively cooled in chamber G.
8. The (possibly cooled) return air then passes through heat wheel E, exchanging heat with the supply air if beneficial.
9. If the desiccant wheel C is fitted and operating, a heating coil D is used to warm the air and regenerate the desiccant.
10. The return air is propelled out of the unit by the return/relief fan AB.

Figure 14: Two stage evaporative cooler – installed

Displacement ventilation

The displacement ventilation is provided via two air handlers, one serving the office spaces and the other serving the classroom areas. The office area systems have an underfloor plenum with a raised floor and swirl diffusers. A high level return air path is used to collect the air back to the air handler.

Each zone is provided with a variable air volume box (VAV) which is controlled to maintain the stratification at the design figure, thereby minimising air volumes. Control zones, shown in different colours in Figure 15, were identified based on occupant density and usage, as well as responding to additional solar heat loads on the northern facades.

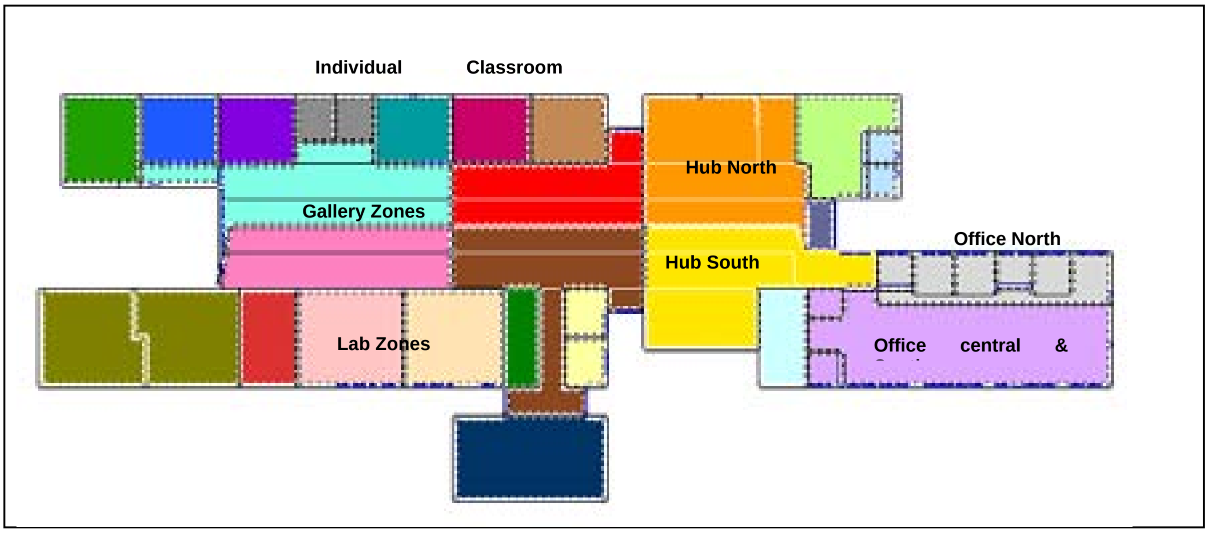


Figure 15: Conditioning control zones (the colours indicate control zones in the simulation model)

The supply air is provided to the classrooms via floor mounted displacement diffusers, while air to the “hub” and “gallery” areas (Figure 16) is provided via a plenum duct built into the floor, using swirl diffusers. Return air is collected via a duct mounted at a high level, with open-able ventilation louvres provided to enable airflow from the classrooms into the Gallery atrium.

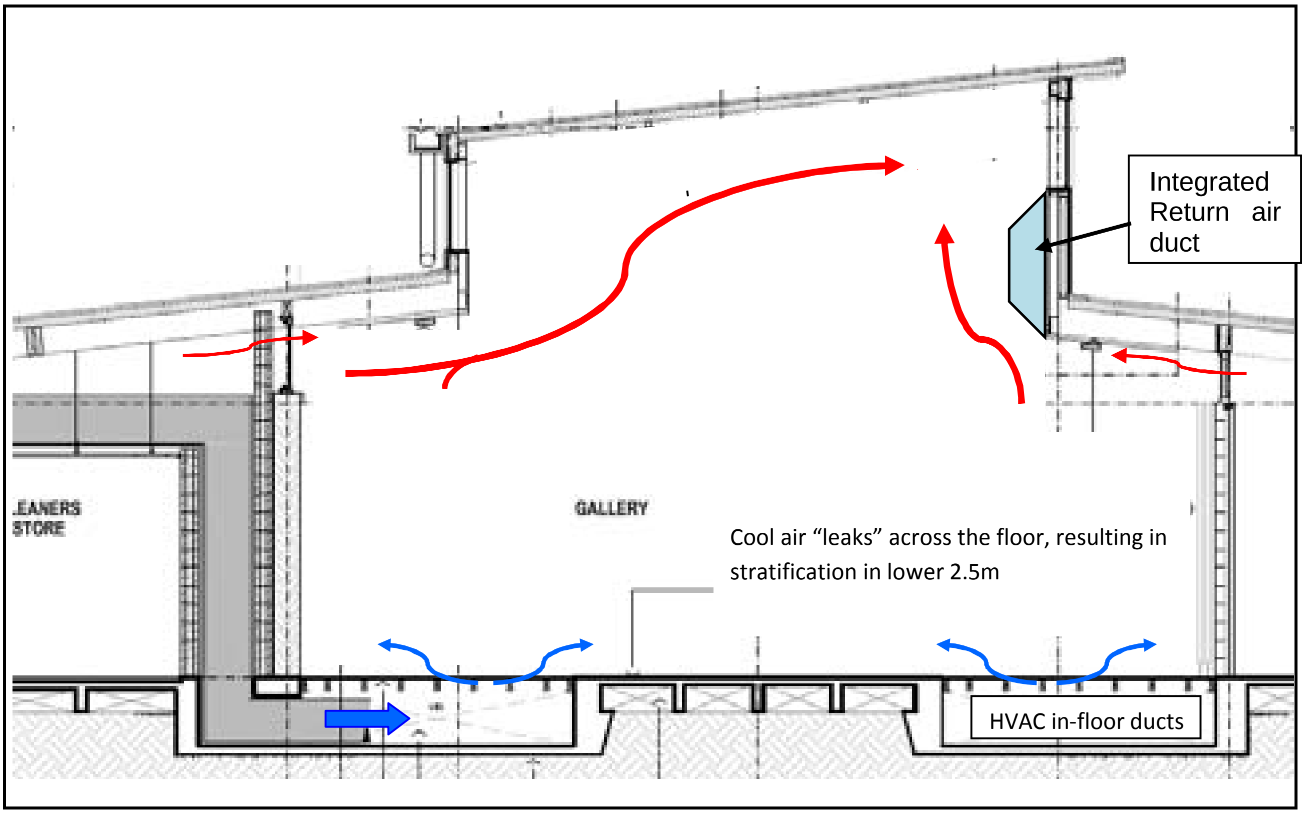


Figure 16: Displacement ventilation in Gallery – cooling mode

Heating System

The heating for the building is provided by a 160 kW condensing boiler operating on a 50°C/30°C temperature range. The initial design allowed for supplementary heating from an evacuated tube solar heating array providing boost heating to the return water. However a review of total GHG emissions determined that this solar boost should be replaced with conventional solar PV panels based on the cost/benefit analysis. This analysis showed that the total reduction of the solar heating array would only reduce the very small heating load during winter, while a PV array would contribute to overall energy reductions throughout the year.

System Operation

The operation of the system is described below:

- Cooling mode. In cooling mode the AHU draws in outside air (potentially mixed with return air dependent upon the comparison of the outside and return air conditions). The heat wheel cools the supply air, if necessary, using evaporatively cooled return/relief air. If the supply air temperature is not achieved, the direct evaporative cooler provides further cooling.
- Natural ventilation mode. When conditions permit, the air handling system is turned off entirely and manually opening windows are used.
- Night purge mode. In night purge mode when outside ambient conditions allow, the automatically opening classroom and high level atrium windows are used to cool the building.
- Heating mode. In heating mode, the outside air is drawn into the AHU, warmed by the heat wheel using the return/relief air, and if necessary heated again by a heating coil.
- A 30kW Photovoltaic array has been installed together with a 5kW vertical axis wind turbine. With these in place and during the shoulder periods when conditions permit natural ventilation, it is expected that the Flannery Centre will be carbon neutral. The predicted

greenhouse gas emissions during the course of the year have been modelled to achieve a low 12.47 kgCO2-e/m^2/yr. A benchmark figured supplied by the Green Building of Australia (GBCA) for this building was 73 kgCO2-e/m^2/yr. This benchmark figure would be taken as 'good' practise and the building would have to meet such a target to be considered for a GBCA star rating.

Note: As a result of a cost control exercise, the desiccant system was not able to be installed for all areas in the initial building design. Allowance has been made for this to be installed at a later date. The decision to postpone this installation was based on the high cost and the simulation results showing that it was expected that the humidity conditions would not be expected to be exceed for more than 3 or 4 days per year.

Conclusions

The iterative design process used in the development of the conditioning system has been both enlightening and taxing on team members. The engineering team members have been challenged on all fronts and had to "go back to the drawing board" on numerous occasions, but have risen to the challenge on each occasion with innovative and well thought out solutions.

The required level of attention to detail and focus on delivering an environmentally sound building envelope and conditioning system during the construction process, unfortunately proved to be too demanding for the appointed builder, to the point where Skillset have taken on the completion of the construction and commissioning of the Flannery Centre themselves.

The indoor/outdoor temperature study has shown that the building envelope has been constructed and insulated in accordance with the design intent. The unloaded building fabric is providing a comfortable and stable environment without the need for conditioning under normal circumstances and that the HAVC system will only be required for the removal of introduced heat loads (occupants and equipment) or for boosting the heating in extended cold periods.

The creative design, practical functionality and innovation incorporated in the design of The Flannery Centre will ensure that it will be a stand out flagship of sustainability for the Central West region and Skillset.

References

[1] Ardren C and Bland A. *Tackling the "We always do it that way" barrier to Environmentally Sustainable Design – an owner's perspective*. (Melbourne, Australia, Achieving the Dream Green AIRAH Sept 2010)

[2] Ardren C, Bannister P and Taylor P. *Underfloor conditioning with heat recovery and evaporative pre-cooling – Flannery Centre, Bathurst NSW*. (Sydney, Australia, AIRAH 90th anniversary conference Nov 2010)

[3] Taylor P, Zhang H, Boland L and Wang G. *Green Star Thermal modelling Flannery Centre, Bathurst, NSW* . 2011.

ASHRAE 2004. ASHRAE 55 – 2004. Thermal Environmental Conditions for Human Occupancy.

Green Building Council of Australia (GBCA) 2008. Green Star Education tool – Energy Calculator

Bureau of Meteorology (BOM) http://www.bom.gov.au/. Accessed 5/3/2008

Performance of a Low Energy Building with Structurally Incorporated Phase Change Material

F. Marlton, P. Bannister, P.A. Taylor, C.M. Ardren

Exergy Australia Pty Ltd

Abstract

The Academic Accommodation Stage 3 Building (AA3) on the Charles Sturt University Albury-Wodonga campus has been designed to be a very low energy building. The two storey building incorporates passive elements which are enhanced through the use of a phase change material (PCM). Cooling is achieved through the use of a cooling tower only, and is supported by a control strategy that is intended to optimise the potential of the encapsulated Micronal® PCM. This material has been incorporated into the building as either plaster board fixed to the underneath of the ceiling slabs or in a floor screed. The hydronic system delivers heating or cooling water as required to the slabs. Natural ventilation is used.

The building was completed in 2010 and has been in full operation since then, with promising results indicating an energy performance of approximately NABERS 6 stars[1]. However the delivery of the building was not without issue, with significant construction, commissioning and operational errors continuing to delay the commencement of effective system operation.

In this paper the issues associated with the delivery of the building are discussed. The thermal comfort performance and energy consumption of the building in heating, cooling, and fully passive operation are reviewed.

Introduction

The AA3 building is a small two storey academic office building of 750 m^2 floor area providing office accommodation for 36-40 staff located in Albury-Wodonga in inland eastern Australia. The performance of the design was predicted via dynamic thermal simulation to exceed the maximum six stars under the NABERS[1] Energy Base Building[2] rating. The building has also achieved a six star Green Star[3] Office Design rating. The design of the building has been described previously [1] and has the following key features:

- Highly insulated to more than double the standard specified by the Australian Building code[4].
- Ultra-high mass construction with reverse-veneer concrete walls, concrete ground slab and ceiling slab, and some concrete partition walls as shown in Figure 1. Additional thermal mass

---

[1] The National Australian Built Environment Rating System (NABERS) is based upon the annual greenhouse gas emissions of a building. The rating is expressed as a number of stars with 2.5 stars representing a market average performance and 5 stars excellent performance. The rating of 6 was recently introduced as a 50% reduction of $CO_{2\text{-eq}}$ emissions from a 5 star building in order to accommodate more recent ultra-high performance buildings [2].

[2] Base building ratings assess the greenhouse gas emissions associated with the energy consumed in supplying building central services (lifts, common area lighting, air conditioning, etc.) to office lettable area and common spaces during the rating period. This is typically the energy under the control of the building owner [2].

[3] The Green Building Council of Australia's (GBCA) Green Star rating system evaluates the environmental design and construction of a building, with 6 stars signifying 'World Leadership' in environmentally sustainable design and/or construction [5].

[4] For the relevant Australian climate zone the U-values of the roof and the walls are specified as minimum values of 0.31 W/m²K and 0.36 W/m²K respectively [4].

provided by incorporation of Micronal® phase change material (PCM) into floor screed and the ceiling lining boards.
- Cooling and heating via a hydronic in-slab piped system circulating hot water for heating and cooled water for cooling.
- Central atrium for daylight access and to permit a degree of overnight natural ventilation.

This design approach was carefully customized to match the inland Australian climate, which is characterized by hot summers (regular temperatures in excess of 30°C, occasional peaks in excess of 40°C), cool winters (mild frosts through winter months) and a diurnal temperature swing of approximately 15°C in summer and 10°C in winter. The controls for the both the heating and cooling modes are as follows.

Heating Mode

In heating mode, the building operates as a highly insulated, high mass building; heating is provided by a small condensing gas boiler sized to provide 34W/m² of heating at 50°C supply temperature. The PCM does not actively participate in heating operation as the use of hot water heating in the slabs results in the PCM being melted at all times.

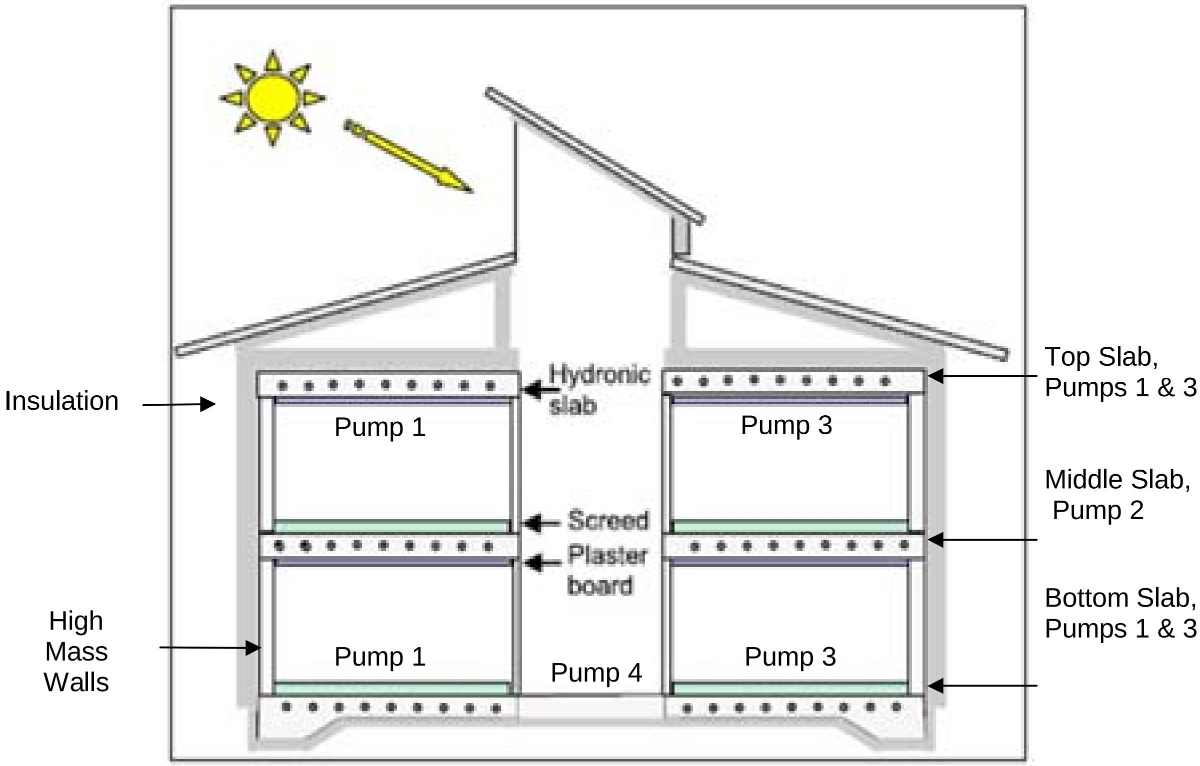


Figure 1. Hydronic layout for the building.

Cooling Mode

The operation of the building in active cooling mode is relatively complex, but is based around simple principles: The cooling tower is operated to circulate cool water through the slabs overnight, cooling the concrete and freezing the PCM. During the day, the building maintains conditions largely through the retention of coolth in the building in the PCM and concrete, supported by the high level of insulation.

The cooling tower may also be used during the day provided that the wet bulb temperature is low enough such that the circulating water can provide a cooling benefit and delay melting the PCM.

Furthermore, a night purge is provided to the atrium area through the use of low and high level automatic vents. Room windows are manually openable for ventilation. However, this strategy does create a risk to the cooling when outside temperatures are high. Four pumps circulate water through the slabs of the building. Pumps 1 and 3 circulate water through the top and bottom slabs for the North and South sides of the building respectively (see Figure 1). Pump 2 circulates water to the middle slab, thereby providing cooling to both levels of the building. Pump 4 cools the floor of the Atrium.

Post Construction History

A variety of avoidable and unavoidable issues have significantly complicated the operational history of the building, including:

- Significant commissioning problems including incorrect pump and valve selections by the contractor;
- Limited hydronic system expertise availability, particularly in a regional location;
- Limited technical support generally, resulting in long problem detection and resolution cycles.
- Apparent underperformance of the cooling tower.
- No initial structured building tuning process, due to drawn out-commissioning problems.
- Organisational changes within the University leading to loss of continuity in operation and management
- Operational errors including the cooling tower being left turned off for the entirety of the 2010/11 summer, and the boiler being operated continuously over the following winter.

These factors have resulted in significantly non-ideal operation for most of the building's history. This study conducted in December/January 2011/2012 has been the first coherent program aimed at getting the information required to enable the building to be properly assessed and operated in cooling mode.

Figure 2. AA3 building. From top, left: northern facade, atrium and southern facade

Study Outline

The purpose of the study was to obtain a snapshot of operation during the summer months. The questions posed were:

1. Is the building functioning correctly?

2. What are the thermal comfort levels being achieved?

3. How energy efficient is the building and does the consumption match the prediction?

To gain the information required to answer these questions a number of sit visits were made and a detailed study of the BMS executed. Whilst visiting the building, measurements were made of the air temperature, relative humidity and the energy meters read. Remote access to the BMS allowed examination of the room air temperature and PCM temperatures in the screed and plasterboard.

The air temperatures of the rooms (zone temperatures) were measured with an air temperature sensor located on the wall, 1.2m above the floor in each room. These sensors, and those located in the PCMs, were thermistors with a resolution of 0.1ºC. The outside air temperature was measured by a temperature sensor located on the roof. A comparison was made between the readings of the Bureau of Meterology (BOM) ambient air temperature and the building's outside air sensor. An average difference of less than 0.2°C between the two sensors was observed.

Thermal comfort depends not just on air temperature, but also radiant temperature. One of the challenges for the assessment of the building's performance is that internal dry-bulb temperature is a poor indicator of comfort due to the fact that the heating and cooling of the slabs significantly modifies the radiant temperature of the indoor environment. Therefore, the Predicted Mean Vote[5] (PMV) was calculated for the zones taking radiant and air temperatures into account as well as humidity, air velocity and assumed CLO and MET values.

In calculation of the PMV the room radiant temperature was estimated from an area weighted average of the surface temperatures. The floor and ceiling temperatures were taken from the BMS. The temperature of light weight walls was assumed to be the same as the air temperature. The window surface temperature was estimated as a function of the inside and outside air temperatures and assumed thin film resistances. The humidity ratio inside the building was assumed to be the same as that outside the building as it is naturally ventilated. No allowance was made for extra moisture content from occupants. Clothing was assumed to be typical office clothing (long-sleeve shirt and trousers, 0.6 CLO). The air velocity was taken as a constant 0.3 m/s representing the operation of the room ceiling fan at low speed.

Study Results

Energy Performance

Figure 3 shows the Base Building Energy Consumption over 2011. The gas consumption for the building is disappointing relative to the original simulated figure of 7.2 GJ and indicates considerable potential for optimization. To date no attempt has been made to optimize this figure as efforts have related to achieving functionality rather than efficiency in the building. This situation has been complicated considerably by ongoing problems in the interpretation of the gas meter readings (which are metered via a private rather than utility owned meter), which have led to significant misunderstanding about the gas consumption for much of the past 2 years; the process of completion of this paper has been the first clear confirmation of the high consumption.

[5] The PMV, as shown in the ASHRAE Standard 55-2004, is a number between -3 (cold) and +3 (hot), which represents the thermal comfort of a person in a room.

The performance of the building as measured under the NABERS Offices Base Building and whole building[6] ratings is just above 6 stars at 6.1 stars in both cases, as summarized in

Table 1. These ratings are estimates only and are not accredited ratings. It should also be noted that the mechanical energy consumption covers this summer and last summer; when the building was not functioning correctly. Given the significant operational issues identified with the building, the high rating is a significant testament to the underlying passive principles of the building design.

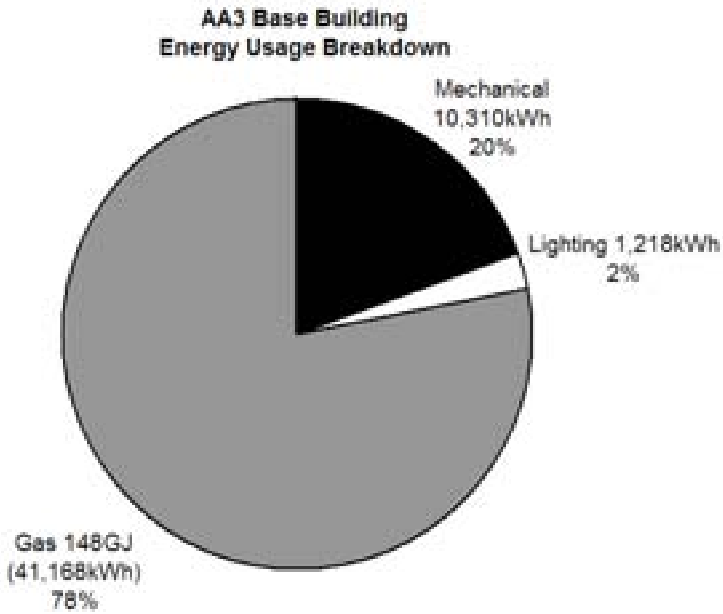


Figure 3. Energy Use Breakdown for AA3 Base Building (Note: excludes tenant light and power, which is a further 29,583kWh)

Table 1: NABERS Rating inputs and outcomes.

Parameter	**Value (Base Building Rating)**	**Value (whole Building Rating)**
Post code	2640	2640
Area (m²)	750	750
Hours of occupancy (per week)	50	50
Computers, number of	n/a	40
Electricity (kWh) per year	11,528	41,111
Gas (GJ) per year	148	148
Intensity (MJ/m²)	252	394
Emissions (kg $CO_{2\text{-}e}$/m²y)	29	72
NABERS rating	6 stars	6 stars
Fractional NABERS rating	6.1 stars	6.1 stars

[6] Whole building ratings assesses the greenhouse gas emissions associated with the energy used by office tenancies and base building services to office lettable area and common spaces during rating period – as the name implies all of the energy consumed by the building [2].

Operational performance – heating

Operation in heating mode has been successful from a comfort perspective, with building temperatures generally well maintained throughout the majority of the building. A sample operating trend for a cold week is shown in Figure 4. The three traces at the top the diagram show the temperatures of the zone (air) and of the ceiling and floor slabs where the PCM is located. The lower traces show the ambient temperatures.

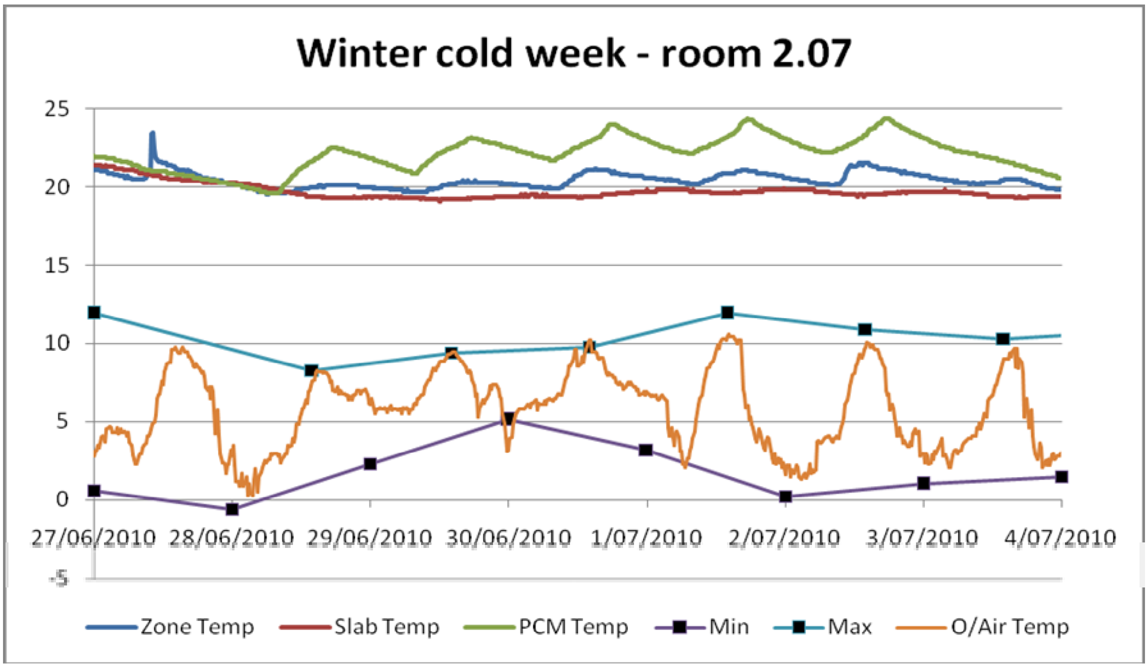


Figure 4. Measured temperature performance in a cold winter week.

It can be seen that indoor temperatures are remarkably stable. Although it would be pleasing to attribute this to the performance of the insulation and mass of the building, investigation of the BMS records reveals that the boiler control was extremely poor over the winter period, with continuous operation occurring, even out of scheduled hours. This explains both the high gas consumption and the remarkably stable comfort conditions. The resolution of this problem will be addressed in the 2012 winter period.

Operational performance – passive cooling

The fact that the cooling tower was not turned on across the summer of 2010-11, while frustrating in terms of the demonstration of cooling system operation, was an excellent demonstration of the robustness of the building's passive thermal performance as shown in Figure 5. In this figure the three traces representing the zone air and PCM temperatures are in the middle of the graph. It can be seen that without cooling, the internal temperatures are warm, but managed within reasonable limits. This reflects the original design strategy, which was the delivery of a building with optimum passive performance as a first priority followed by the addition of low energy active systems to supplement this passive performance. The occupancy over this period was estimated at approximately 50%.

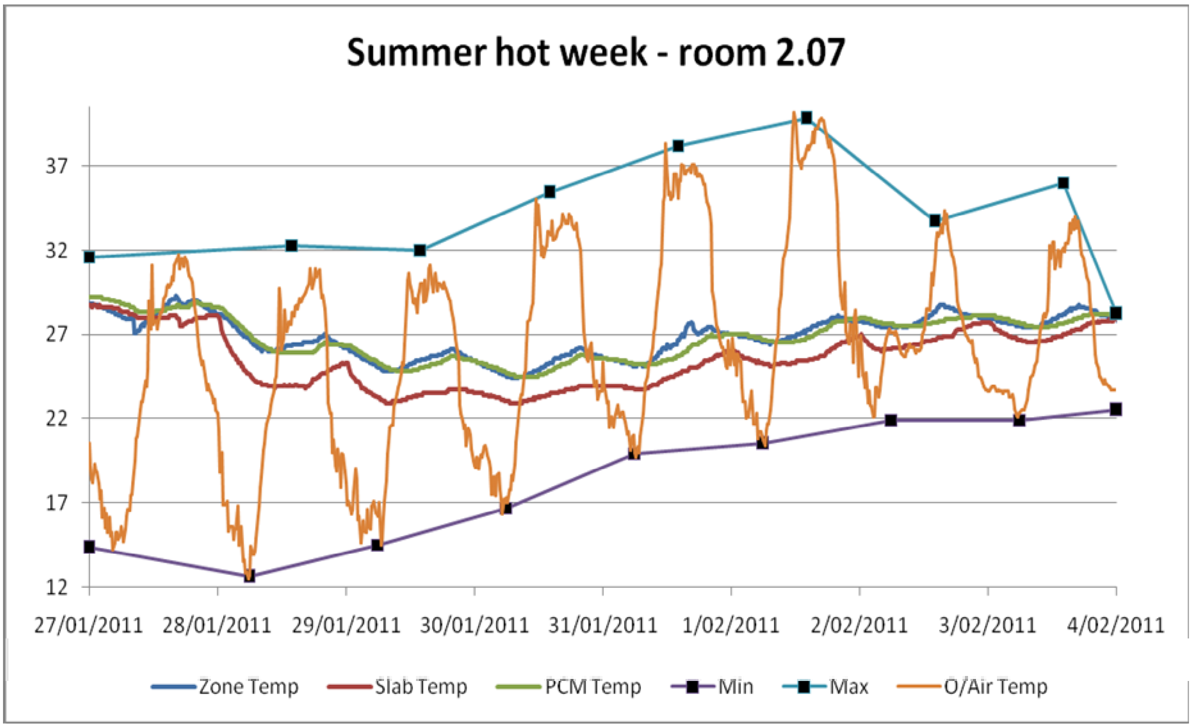


Figure 5. Measured operation of the building in summer without the cooling system operating.

Operational performance – active cooling

In the period covered by the investigation presented in this paper, Pump 1 had failed. This has meant that the north side of the building has no active cooling. As a result, the building was operating in passive mode for the north side and active cooling mode for the south side. This allows for a comparison to be made between the two sides of the building to see whether the design of the building can effectively achieve thermal comfort. Data was collected over the 2011/12 summer and a hot (maximum outside air Temperature > 33°C) period in January 2012 was selected for analysis as illustrated in Figure 6.

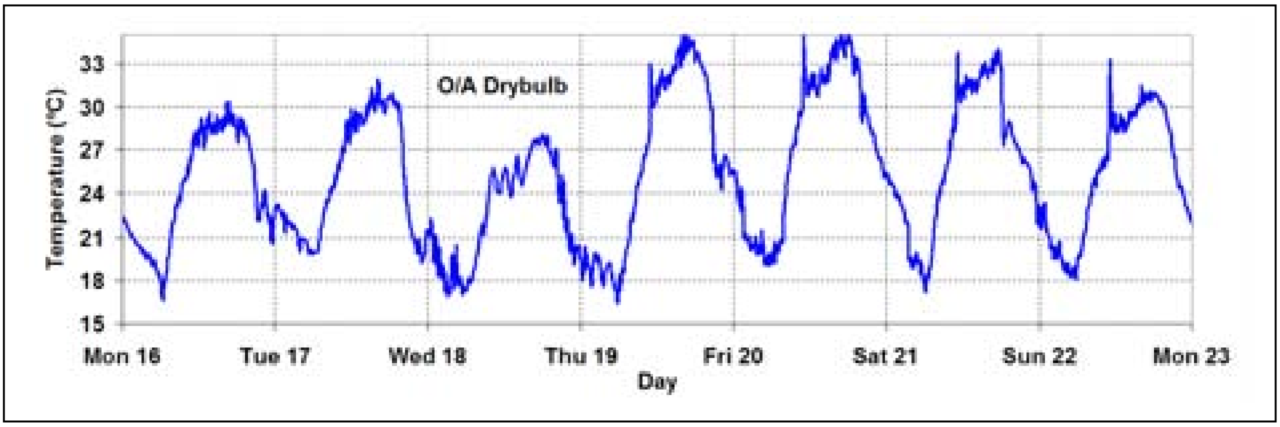


Figure 6. Outside Dry Bulb Temperatures for hot period

Ground Level Cooling Performance

Figure 7 shows the radiant temperature, dry bulb temperature and PMV with an assumed air speed of 0.3 m/s for two rooms on the ground floor of the building. Room 1.15 is on the North side whilst Room 1.11 is on the South. There was only a small difference in solar load between the two rooms, due to window set backs and overhangs, making them very similar for comparison (see Figure 2).

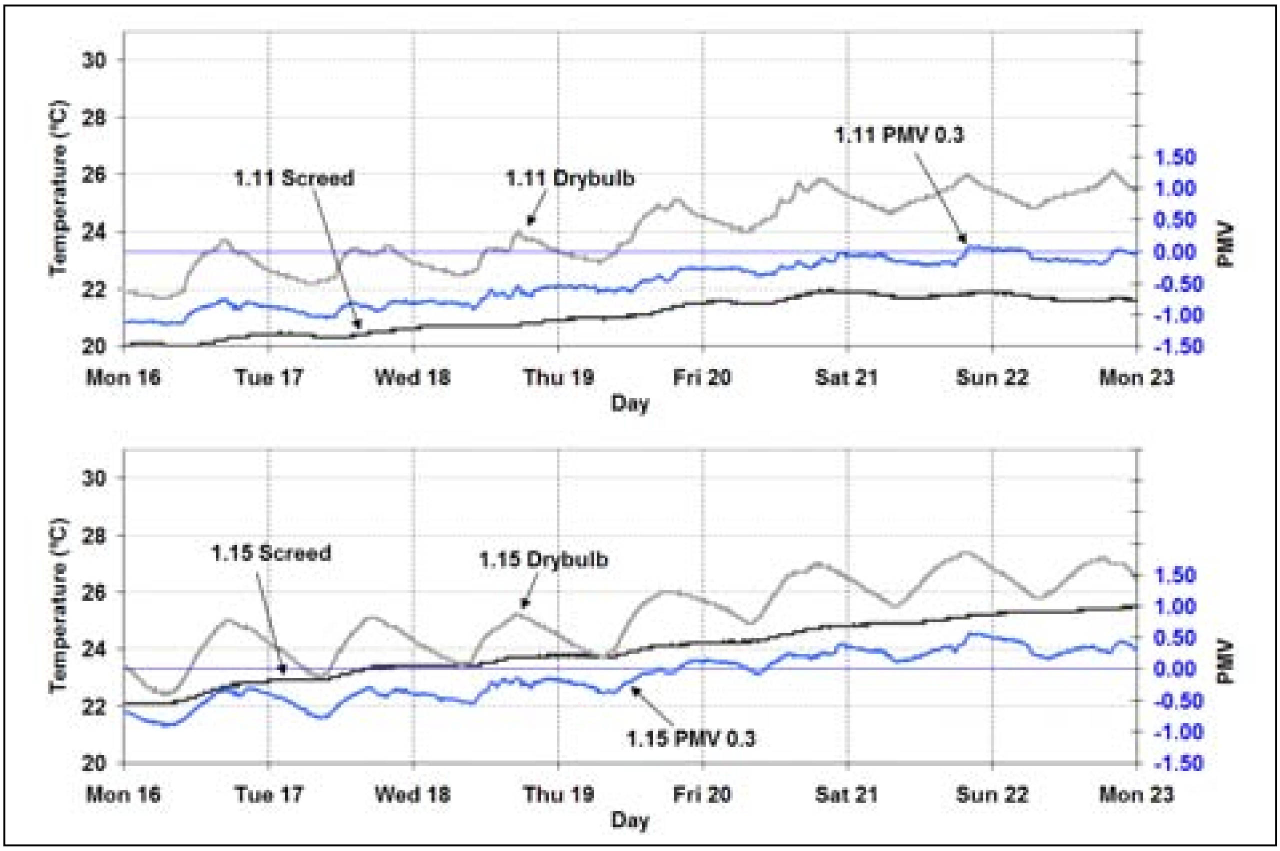


Figure 7. Example of cooling mode operation in rooms 1.11 (South, actively cooled) and 1.15 (North, passively cooled).

It can be seen that there is only a slight difference in the radiant temperature between the two sides of the building. Both have achieved thermal comfort with the South side being generally more comfortable. This is due to the lower screed temperature of the South side created by the functional pump. However, it is also notable that there is evidence of possible overcooling in the South side, although it should be noted that allowing the air velocity to drop to zero (by turning the ceiling fan off) would increase the PMV by approximately 0.45, largely countering this effect.

In general however, it is evident that the ground floor performance is largely driven by the passive performance of the building, with the active cooling providing only limited benefit.

Level 1 Cooling Performance

Figure 8 repeats the presentation of Figure 7 for two rooms on Level 1 of the building, being rooms 2.07 (south, actively cooled) and 2.18 (north, passively cooled).

It can be seen this level of the building is significantly warmer than the lower level, due presumably to hot air rising in the building (which is particularly prevalent due to the lack of any multi-zone ventilation system) and the lack of contact with the ground. The associated higher cooling loads enable the effectiveness of the cooling system to be seen clearly, with a large difference in the PMV for each of the rooms becoming apparent as the building warmed to towards the end of the measurement period. The south side room has achieved excellent thermal comfort while the passively cooled room has become marginally too hot.

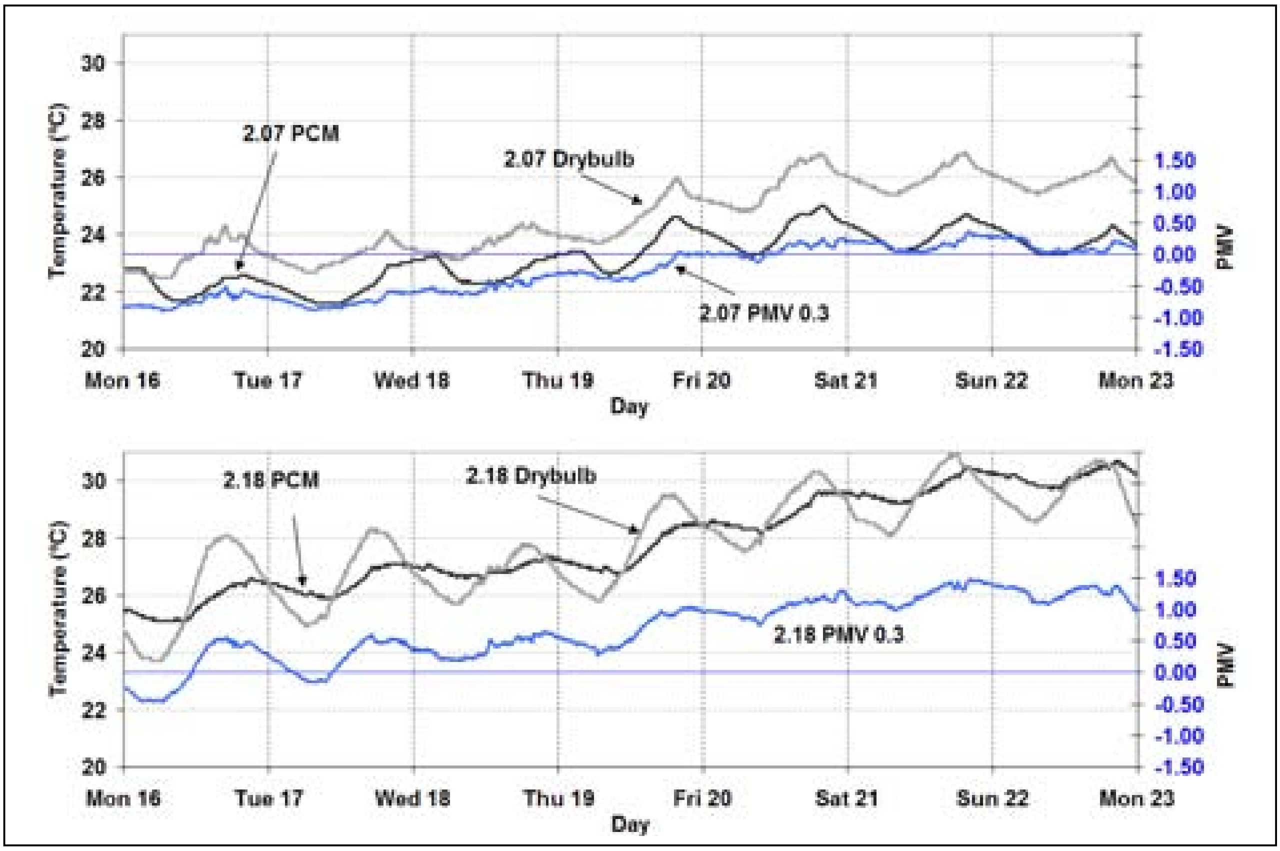


Figure 8. Example of cooling mode operation in rooms 2.07 (South, actively cooled) and 2.18 (North, passively cooled)

Atrium cooling performance

The atrium is cooled hydronically as with the rest of the building but the large void means that the upper level, in particular, has limited hydronic cooling capacity. However, the atrium is also equipped with automatically opening windows at either end and ventilation chimneys under automatic control for use in cooling when conditions permit; in summer this is typically overnight only due to high external temperatures. Operation of the atrium over the three hottest days of the measurement period is shown in Figure 9.

It can be seen in Figure 9 that the overnight temperature in the atrium is only dropping by about 2-3°C, suggesting that the night purge is at best marginally effective. There are several potential reasons for this: the high mass of the building means that high airflow rates are required to achieve significant temperature reductions; the overnight air temperature during the measurement period is high (the average January overnight for the area is 15°C); and the overnight wind speed is very low, resulting in ventilation being driven by stack effect only. This latter effect was noted in earlier naturally ventilated buildings on the campus by Taylor [3].

While these effects are inherent to the location, it is noted that there is also a rectifiable construction error in the building that further hinders overnight airflow – a large daylight baffle has been built which significantly restricts the airflow to the ventilation chimneys. The baffle was built with little consideration of ventilation, and would require significant modifications to introduce the required air paths.

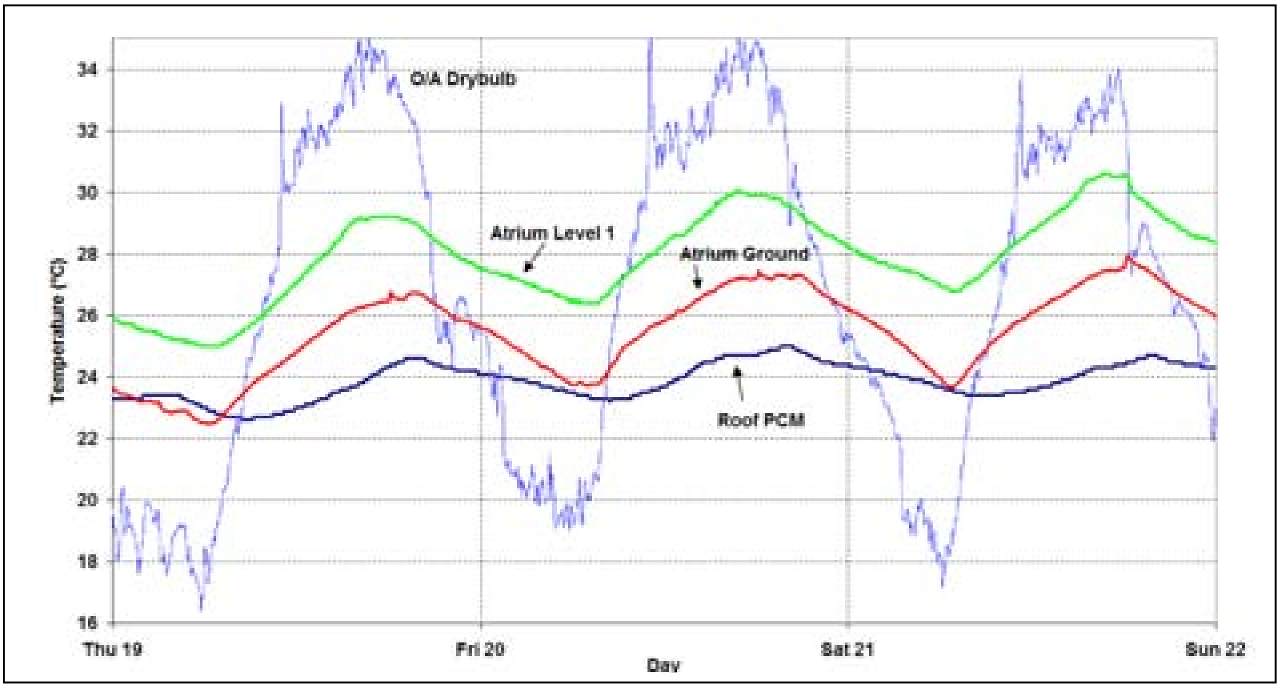


Figure 9. Ground and 1st Level Atrium, Southside Top PCM and outside air Temperatures for the three hot days where the maximum temperature was above 33°C

Review of cooling controls

The control of the building as configured is relatively complex due to the perceived need to control dry-bulb temperature while only being capable of direct variation of radiant temperature. This is further complicated by the operation of the PCM, for which the melt/freeze cycle plays an important role in the cooling control. The building operation during the assessment period illustrates a number of issues with the control operation, as illustrated in Figure 10:

- The presence of actual phase change is remarkably difficult to determine from the measured temperatures. The Micronal® PCM has a melt temperature of approximately 21 - 23°C, which in theory should lead to a temperature plateau at this temperature. It can be seen that there is evidence of this in the ceiling PCM readings in the first few days, but the top PCM shows no such evidence in spite of passing through much the same temperature region.

- If it is conjectured that the melt occurs in the region of 21-23°C, it can be seen that, in the latter half of the week, three out of four slabs were continuously melted while the remaining slab had continuously frozen PCM. The middle slabs, in particular, warm up substantially. This issue was traced to a faulty sensor which was distorting the control zone temperature; as a result the middle slab pump (pump 2) did not operate. Thus the generally satisfactory south zone cooling results demonstrated in Figure 7 and Figure 8 were achieved largely without the benefit of middle slab cooling.

- The continuously frozen bottom slab is the result of two effects, being firstly the lack of valve control in cooling mode, which results in the bottom slab being cooled whenever the top slab is cooled, and secondly the lower loads in the ground floor. It would make considerably more sense for the bottom slab temperature to be allowed to drift independently of the top, particularly given the evidence of possible over-cooling in the ground floor in Figure 7.

- The apparent failure of the PCM in the top layer to freeze overnight in the latter half of the assessment period indicates a problem with capacity. This could be partially rectified if the bottom slab on the ground floor was valved off so that all cooling could be provided to the top slab in the ceiling of the upper level.
- In general, it would be preferable for the middle slab cooling to be prioritized over the top and bottom slab cooling, as this could then be indexed to the cooler of the two levels while permitting the top slab (typically) to be operated to provide supplementary cooling.

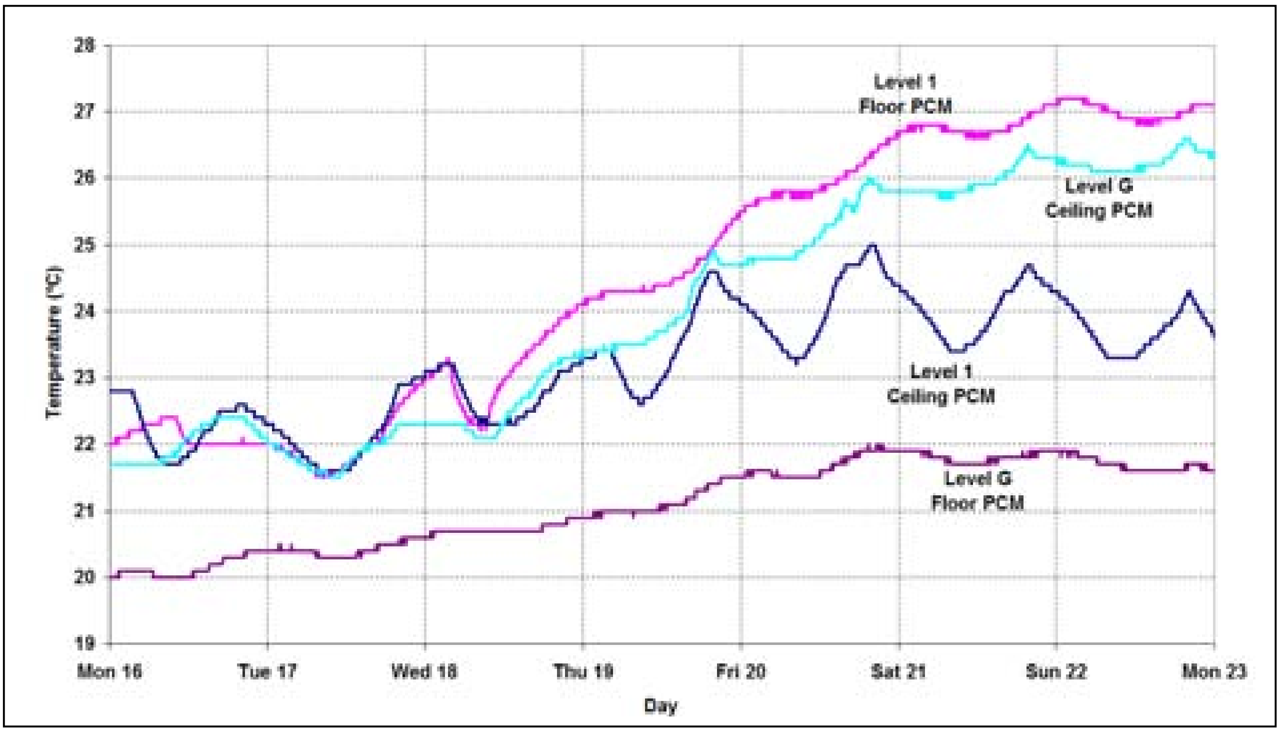


Figure 10. PCM operation during the assessment period. 'Level G PCM' and 'Level 1 Ceiling PCM' correspond to the south bottom and top slabs respectively. 'Level G Ceiling PCM' and 'Level 1 Floor PCM' correspond to the lower and upper PCM layers in the south middle slab respectively. All PCM temperatures were assessed by temperature sensors embedded within the layers of PCM or PCM-enriched material.

Conclusions

The Academic Accommodation Stage 3 building at the Albury-Wodonga campus of Charles Sturt University was designed as an innovative, low-energy building utilizing structurally incorporated PCM cooled by an in-slab hydronic, serviced by a cooling tower. The building has been operational for two years.

Controls

In general, the review of system operation versus design intent strongly suggests that the controls for the building require simplification. This is further indicated by the problems experienced in the management of the building, which indicate that the facilities staff tasked with management of the building have very little understanding of how the building was intended to work.

The largest potential simplification is suggested by the comparison of dry-bulb to radiant space temperatures in Figure 7 and Figure 8; it can be seen that the coupling between the screed/PCM temperatures and the dry-bulb temperature is relatively weak. This implies that a far cruder methodology of control could be instigated using predicted weather data for the following day to choose to freeze the middle slab, the top slab and the bottom slab. With a little tuning this could largely supplant many of the complex algorithms currently in place. As the BMS is web-server connected, obtaining predicted temperatures one day ahead is relatively straightforward.

Operational Issues

The building stands somewhat as a testimony to the problems that can arise when building an innovative – and thereby unusual – building. The regional location of the building had a major impact on the availability of quality contractors to deliver to the level of refinement needed for the system, and the distance of the design team from the site meant that the resultant construction issues were not always resolved in a timely manner. Furthermore, changes in management at the site caused significant disconnects in the commissioning and operation of the building which have impacted on its ability to operate effectively in the first two years.

Hand-over has also been poor at occupant level, with staff occupying the building having a very poor understanding of the building (ironically, most thought that the building was a naturally ventilated building like a number of others on the campus, because of the invisibility of the hydronic cooling system). This may have contributed to a general tendency for problems on site not to be recognized or corrected.

The monitoring over the next year is intended to resolve a number of these issues and put the building on a more stable operational basis.

Acknowledgements

This paper forms part of the Bachelor of Engineering Honours thesis work being conducted by Frederick Marlton at the Australian National University. The project would not have been possible without the ongoing assistance of Ed Maher at Charles Sturt University.

References

[1] Bannister, P, Taylor, P, Ardren, C, Schmidt, M. *Design and control of a building with structurally incorporated phase change material.* Proc. of the IEECB 2008 Conference (Frankfurt, April 2008).

[2] www.nabers.com.au

[3] Taylor, P, 2005, Energy and thermal comfort in a rammed earth office building, *A thesis submitted in fulfillment of the requirements for the degree of Master of Architecture Deakin University*, Waterfront campus, Geelong, Australia

[4] Australian Building Code Board. (2011). *National Construction Code Series Vol.1: Building Code of Australia 2011 Class 2 to Class 9 Buildings.*

[5] www.gbca.org.au

Performance of an energy efficient glazed office building in Sweden

Åke Blomsterberg, MSc PhD

WSP Environmental and Energy and Building Design, Lund University, Sweden

Abstract

Many modern office buildings have highly glazed facades. Their energy efficiency and indoor environment is, however, often questioned. Therefore, when a modern office building (new construction) with larger glazing areas than traditionally was to be built, the aim of the design was to

- efficiently use the increased access to daylight and thereby reduce the use of electricity for lighting and at the same time improve the visual comfort
- ensure a good thermal comfort
- arrive at a reasonable total energy use, which is at a lower level than a traditional new modern Swedish office building

During the design advanced energy, indoor climate and daylight simulations were carried out against performance specifications on energy use and indoor climate.

The performance monitoring during 2010 shows that it is possible in a more efficient way than is often the case, to utilize the greater access to daylight and reduce electricity consumption for lighting. This while the visual comfort is improved, a good thermal indoor climate is ensured throughout the year, and a reasonable energy use is achieved, which is the same as for a modern office building with a traditional glass portion. The aim with regard to low energy use has not been fully attained. This can be partly explained by lower real efficiency of heat recovery on ventilation than in the design, other activity profile including lower attendance rate than assumed at the design stage, somewhat lower real U values for windows, narrower set points for indoor climate than assumed, however, night cooling that was not assumed at the design.

Introduction

Many modern office buildings have glass facades. Architecturally an airy, transparent and light building with insight and outlook is created, where access to daylight is greater than in more traditional office buildings. The idea is often to create a building with openness and appearance of future. Glass Buildings symbolizes both technology development and profile projects. This has meant that there still is a demand for glass offices. However, energy use and indoor climate in these buildings are often questioned.

A detailed follow-up during the design of a new office with glass facades [1] has shown that it should be possible to ensure good thermal and visual comfort and to achieve a total energy use, which is the same as for a traditional modern office building. This can be achieved by reducing the glass area, improving glass façade U-values and shading. In order to further reduce energy use the glass area, U-value and internal heat gains must be reduced further. This is studied in detail in an ongoing research project "Energy-efficient office building with low internal heat gains - Simulations and design guidelines" at Energy and Building Design at Lund University.

This new office is now operational in Malmö since November 2007 and was followed up during the winter of 2009/2010 [2]. In addition, an environmental classification according to Environmental Building (Swedish rating system) for existing buildings has been carried out, which is expected to arrive at environmental class silver.

Description of the building

At an early stage performance requirements on energy use and indoor climate were drafted. Estimates and advanced calculations were carried out of energy use, indoor climate and daylight. Experts from the research project Office buildings in glass - Energy and indoor climate, at Energy and

Building Design at Lund University, www.ebd.lth.se, participated. WSP was responsible for the architectural design of the building, and all technical designs. The developer Midroc is also facility manager of the building.

The heating demand was minimized by good insulation and air tightness. All surfaces that are not transparent are fully insulated, the windows facing east, south and west have relatively low U-values and low solar transmittance incl. Venetian blinds. Convectors at the windows have been installed to reduce the cold down draught, and ventilation is demand controlled. An occupancy sensor in each supply air terminal device ensures that the airflow is reduced five minutes after a room or office space is empty. The ventilation is reduced during evenings, nights and weekends.

The energy efficient lighting fixtures at the south facade, are automatically dimmed i.e. the more daylight the less artificial light. All individual light fittings are switched on manually and turn off automatically 20 minutes after an office space or room is empty. This is done by means of the aforementioned presence sensor.

Daylight and solar gains through windows are controlled both by solar protection glass and automatic Venetian blinds in the air gap between the glass surfaces of the south, east and west facade, which is a so-called double skin facade. The position of the blinds means that the solar shading is protected and can be used regardless of weather conditions and pulled up when not needed. Too much light and / or excessive contrasts of daylight make it difficult to read on computer screens.

The building is heated by district heating. The planned district cooling was not chosen because it does not allow cooling with outdoor air (free cooling) from the demand controlled ventilation system. If necessary, a cooling unit will cool the supply air.

Features of the building:

- Total floor area 8064 m² (premises) or 8574 m² (heated floor area) excluding garage.
- Number of floors is 5.
- High air tightness of building envelope, according to measurements 0.7 l/sm ² at 50 Pa [3]
- Low U-values for roof, walls and floor: incl. thermal bridges of 0.12, 0.22 respectively. 0.32 W/m²K. The average heat transfer coefficient, for the structural elements that enclose the building is 0.55 W / m² K.
- Windows with low U-values: 1.1 to 1.3 W / m² K
- Reduced glass area, about half of the facade surface
- Double skin façade.
- Efficient solar shading with solar control glass combined with external variable shading (the total solar transmittance g_{system} = 0.1).
- Demand controlled ventilation (VAV)
- Free cooling with ventilation, especially night ventilation
- Low use of electricity for tenants due to absence controlled electrically efficient lighting and laptops

Method

The monitoring of energy use and indoor climate included a follow-up during the operating phase, efforts beyond what is included in traditional monitoring during the operating phase. This was done by measuring and evaluating energy use, the thermal indoor climate and visual comfort in 2010.

The evaluation period began with performance checks, then continuous measurements during 1 year were carried out. The continuous monitoring during 2010 focused on energy use, indoor temperature and outdoor climate. Long-term measurements were carried out using BEMS (Honeywell) and BEMS for room climate (LindinVent system for demand-controlled ventilation, which controls and monitors indoor climate). Most values were recorded as hourly values.

The monitored energy use was evaluated by calculations with a validated dynamic building energy simulation program, IDA ICE 4 [4]. The original IDA model of the building was developed during the design work.

Results and discussion

Design experience

To create an energy-efficient office building with good indoor climate a holistic approach is required in which the building is considered as a system consisting of the building, installations, activity and users. This has to coordinated and ensured for all designers. During the design of a glass facade, there are many pitfalls, which if not avoided, could result in a high energy use, problems with the indoor climate and visual comfort [5]. Very important parameters are the glass fraction, g-values (including shading), U-values (including profiles), daylight transmittance and control of the glass facade (solar shading and light control). A building with glass facade is more sensitive to errors than a building with a traditional facade. Therefore, extra careful planning, careful construction, careful commissioning and careful operation of the building are required. Careful planning includes: advanced energy, indoor climate and daylight simulations.

Measured air flows

Continuous measurements of air flows using the BEMS for room climate (the system of demand-controlled ventilation) shows that the average air flow for the entire building in 2010 was 0.62 l/sm² Atemp during business hours and 0.26 l/sm ² Atemp (see Table 1) outside business hours . The measured airflow during business hours, can be compared with a commonly used normal value of 1.5 l/sm ² Atemp without demand control [6].

Table 1 Measured air flows for the whole building, May 2010 – March 2011.

	Office hours 7-18, l/s	Maximum air flow, l/s	Non-office hours, l/s	Office hours 7-18, l/s, l/sm² (A_{temp})	Maximum air flow, l/sm² (A_{temp})	Non-office hours, l/sm² (A_{temp})
October-March	4 377	12 000	721	0,51	1,40	0,08
May-September	6 473	17 000	4 020	0,75	1,98	0,47
Whole year	5 330		2 221	0,62	1,98	0,26

Measured presence

By continuous logging of presence sensors in the supply air terminal devices the degree of presence in the office building could be determined to be 42% between the hours of 7 and 18 for weekdays during the summer. The corresponding value between the hours of 7 and 18 for weekdays during the autumn-winter-spring period was determined to be 52%. This means an average attendance rate throughout the year for weekdays 7-18 of 50%, which translated into at 8-17 is 60%. The commonly used recommendation is 70% [6].

Energy use

During 2010 the district heating use was measured to be 603 MWh, which corresponds to 70 kWh/m²(Atemp) (see the distribution during the year in Figure 1). Property electricity use including electricity use for cooling was 215 MWh, which corresponds to 25 kWh/m² (Atemp), of which 8 kWh/m² (Atemp), is electricity use for cooling. This implies a total energy use of 95 kWh/m² (Atemp), compared with the requirement of the Swedish building code of 2011 of 100 kWh/m² (Atemp) (airflow correction gives a requirement of 119 kWh/m² (Atemp)) and was originally estimated to 67 kWh/m². Measured tenant electricity use is 322 MWh, which corresponds to 38 kWh/m², of which 13 kWh/m² goes to lighting. This compares with the value assumed in the original calculations of 46 kWh/m², which can be compared with the normal value of 50 kWh / m² [6].

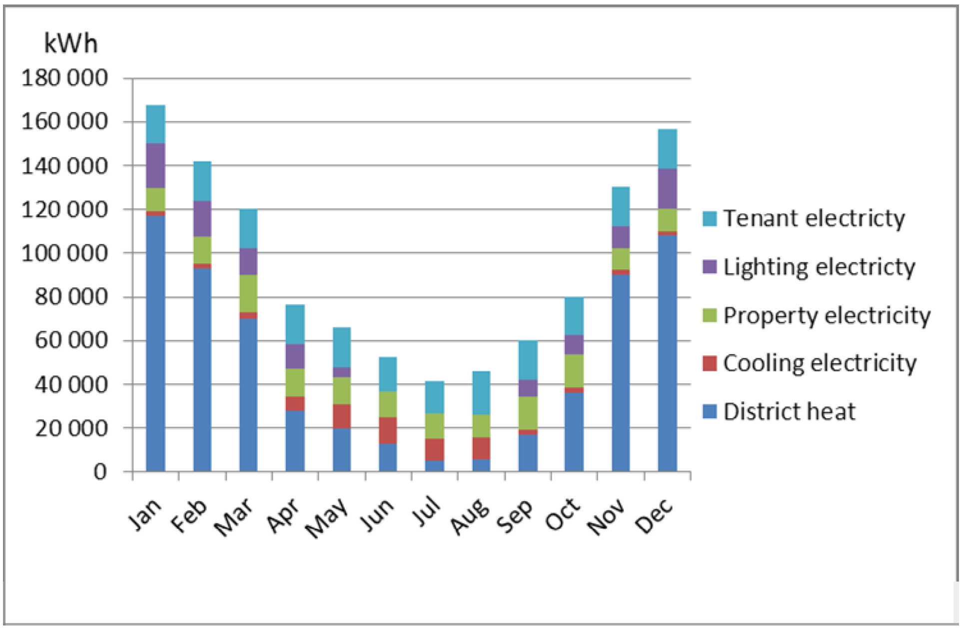


Figure 1 Measured energy use during 2012.

Measured electricity use is substantially lower than the average of 123 Swedish office buildings of varying age [7] (see Figure 2).

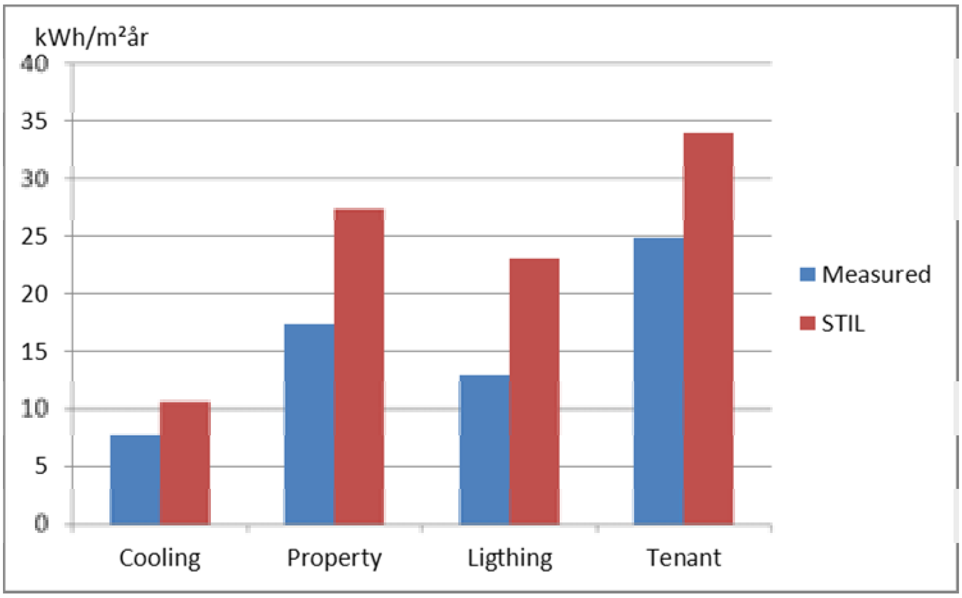


Figure 2 Comparison between measured use of electricity and use of electricity according to the STIL-survey of 123 office buildings [7].

The total annual energy use according to the original calculations was 769 MWh, the measured for the year 2010 is 1140 MWh and for the year 2010 calculated applying actual operation is 993 MWh. The difference between the initial estimate and measured is due to:

1. level of heat gains from persons, actual average presence was 60% of 188 persons and assumed was 80% of 431 people during office hours.

2. real set points for cooling respectively heating was 22 °C, respectively 21 °C, and calculated 24 °C, respectively. 22 °C.

3. efficiency of heat recovery, calculated 75% and real about 45% according to estimates from operational and product data. The difference in efficiency is mainly due to the fact that coil heat exchangers were installed instead of rotary heat exchangers.

4. the actual building is slightly larger

5. different outdoor climate, colder winter and warmer summer in 2010

The difference between measured and estimated for 2010 is primarily a difference in heating use. Precise agreement between theory and reality are seldom achieved, but this deviation is unusually large.

If the original requirement for the efficiency of heat recovery of 75% had been met, and set point requirement for cooling at 24 ° C, the total energy use had dropped from 116 kWh/m² year to 92 kWh/m² year Malmo in 2010. The use of district heating would have been reduced from 53 kWh/m² year to 35 kWh/m² year and electricity use for cooling from 9 kWh/m² year to 8.5 kWh/m² year (see Figure 3).

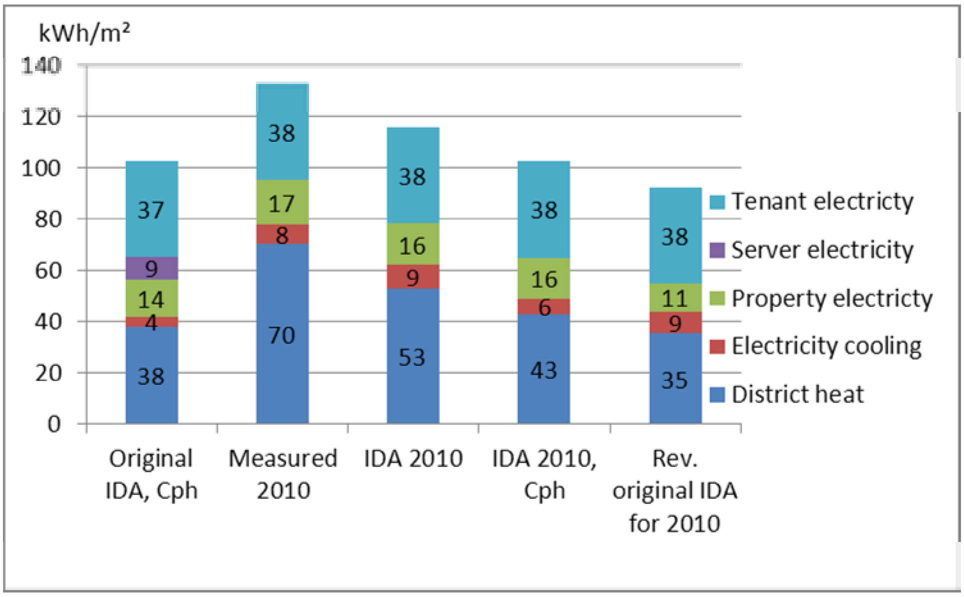


Figure 3 Calculated and measured energy use. Only for the original calculation the energy use of servers is presented separately. For the others the use of electricity is included in the tenant's electricity.

The total specific energy use is:

- 103 kWh/m²(Atemp)year according to the original IDA calculation for the reference climate for Copenhagen. Assumed cooling is converted to electricity for cooling.
- 133 kWh/m² (Atemp) year according to the measurements in 2010.
- 116 kWh/m² (Atemp) year according to the IDA calculations for 2010.
- 103 kWh/m² (Atemp) year according to the IDA calculations with operation according to the year 2010, but for the reference climate for Copenhagen.
- 92 kWh/m² (Atemp) year according to the IDA calculations for the year 2010 if the efficiency of heat recovery would have been 75%, the set point for cooling had been 24 ° C.

It is interesting to see the importance of climate. 2010 has clearly had a colder winter and warmer summer than the reference climate for Copenhagen, which resulted in 53 kWh/m² (Atemp) year instead of 43 kWh/m² (Atemp) year for heat and 9 kWh/m² (Atemp) years instead of 6 kWh/m² (Atemp) year for electricity to cool.

If the specific energy use is specified as in the Swedish building code i.e. energy delivered to the building for heating, cooling, hot water and building property electricity the specific energy use will be:

- 56 kWh/m² (Atemp) years according to the original IDA calculation for the reference climate in Copenhagen
- 95 kWh/m² (Atemp) years according to the measurements in 2010
- 78 kWh/m² (Atemp) years according to the IDA calculations for 2010
- 65 kWh/m² (Atemp) years according to the IDA calculations with operation according to the year 2010, but for the reference climate for Copenhagen
- 55 kWh/m² (Atemp) years according to the IDA calculations for the year 2010 if the efficiency of heat recovery would have been 75%, the set point for cooling had been 24 °C.

The difference between IDA calculations for 2010 is 23 kWh/m² (Atemp) year (78-55), which means that the actual building with better heat recovery and raised set point for cooling should be able to at least achieve an energy use of 72 kWh/m² (Atemp) year for Malmö climate in 2010 or about 62 kWh/m² (Atemp) years for the reference climate for Copenhagen. If the measurement had been carried out for a similar climate to the reference climate for Copenhagen the measured energy use would probably have been 79 kWh/m²(Atemp) year.

Measured indoor temperatures

The two parts (the WSP part supplied by one air handling unit and non-WSP part supplied by another air handling unit) of the office building are very similar as to air temperatures and fulfills the specified requirements (see Table 2). The temperature variation within the building, between different levels and different rooms, is small.

Table 2 Measured number of office hours with temperature above 26 ° C.

WSP	May - September, north facade	9
	May - September, south facade	3
non-WSP	May - September, north facade	3
	May - September, south facade	3

Questionnaire – thermal comfort

The response frequency to the questionnaire (EcoEffect www.ecoeffect.se - workplace questionnaire), was a total of 75% after two reminders. When asked if you are disturbed by the following problems with the heat at your workplace, less than 5% are disturbed apart from three types of problems that are at a higher frequency of disturbance (see Figure 4). About 30% say they are often disturbed by it being too cold in the winter months, which may be due to the large glass facades.

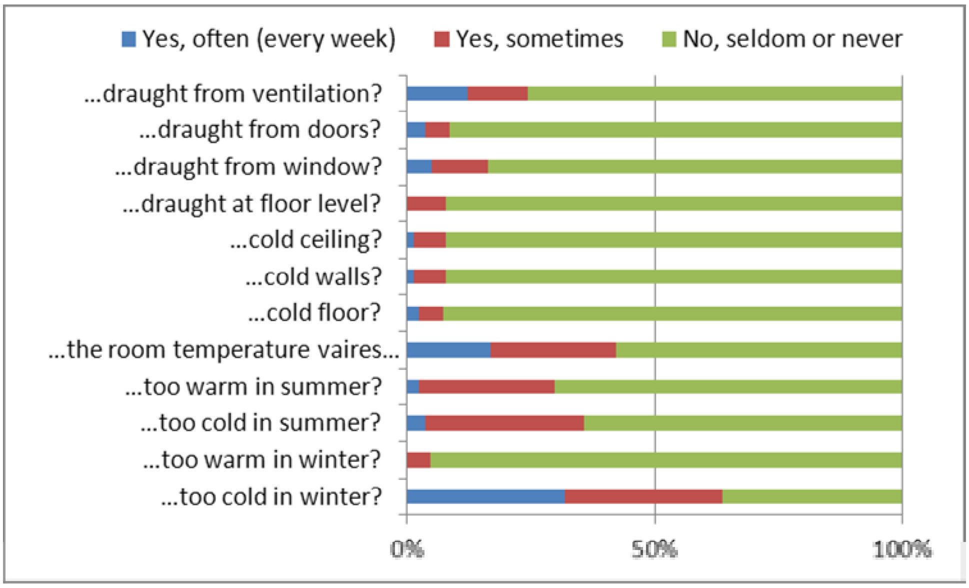


Figure 4 Results from the questionnaire – Does it happen that you are disturbed by the following problems with the heating at your workplace ...?

Questionnaire - sound

As to the sound environment, less than 10% are disturbed by different types of noise (see Figure 5). However, there are types of sounds for which the disturbance frequency is disturbingly high, namely speech/voices from the adjoining room with a complaint frequency above 50%, noise from the hallways with a complaint frequency of about 30%, and the echoing sounds of speech and voices in the room with a complaint frequency of about 20%. The first two problems were due to deficiencies in the sound insulation above the suspended ceiling, which was resolved after the survey.

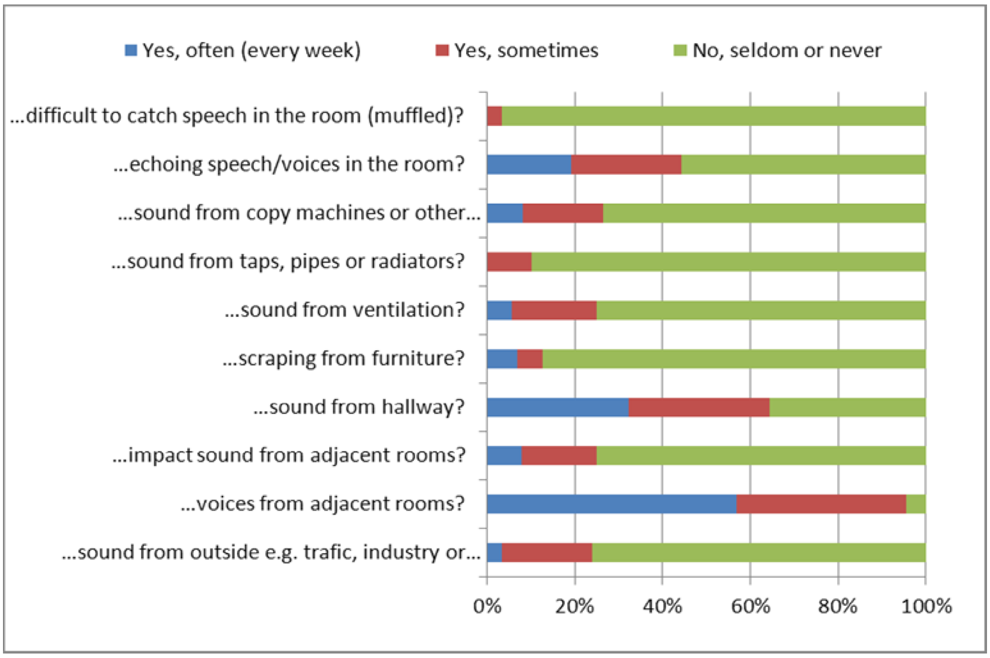


Figure 5 Results from the questionnaire _ Does it happen that you are disturbed by the following sound at your workplace ...?

Interestingly, only 6% of the respondents are bothered often by noise from the ventilation. This is despite the fact that the ventilation is demand controlled and thus the size of the ventilation flows vary over time.

Questionnaire – light

As to the visual environment, less than 10% are disturbed by various types of light (see Figure 6). These are good values, especially considering that this is a glass office. Apparently the control of daylight with automatically controlled Venetian blinds and the absence controlled and daylight compensated lighting system are largely satisfactory. However 40-50% are disturbed, of which about 1/5 sits at the north facade, often/sometimes of solar reflection and too much direct sunlight.

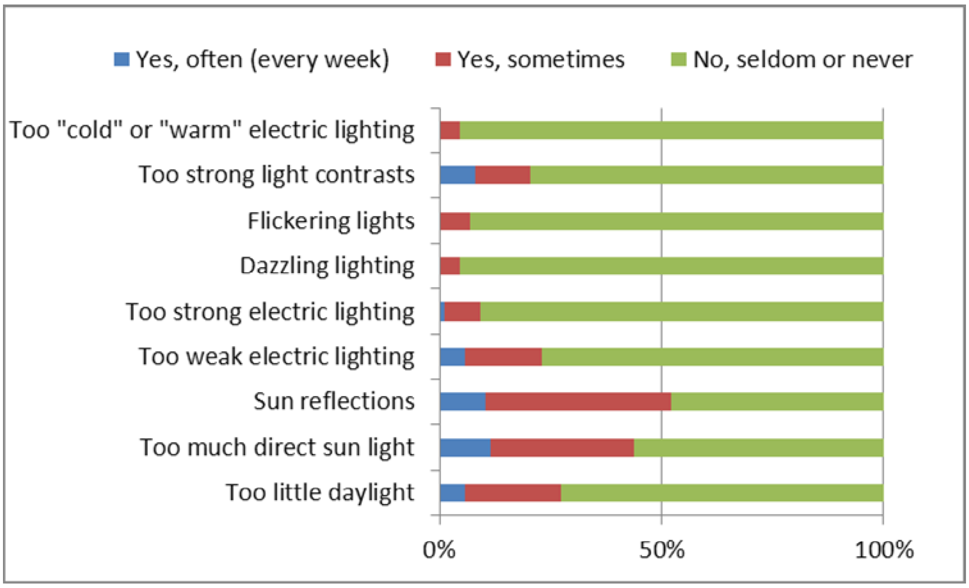


Figure 6 Results from the questionnaire – Does it happen that you are disturbed by the light at your workplace …?

One problem that may arise in particular in a glass office is problems reading the computer screen. The survey shows that less than 5% often experience eye or visual problems when reading or working with the computer screen. Approximately 25% sometimes experience eye or vision problems.

Conclusions

The project shows that it is possible in a more efficient way than is often the case, to utilize the greater access to daylight and reduce electricity use for lighting. This while the visual comfort is improved, good thermal indoor comfort is ensured throughout the year, and a reasonable energy use is achieved, which is the same as for a modern office building with a traditional glass area. The visual comfort could be improved further by including a glare curtain on the glazed north façade, better control of the Venetian blinds or supplementing with glare curtains on the other facades.

The aim with regard to energy use has not been fully met for the studied office building. This can be partly explained by lower real efficiency of heat recovery on ventilation than assumed in the planning, other activity profile e.g. lower attendance rate than assumed at the design stage, somewhat lower actual U values for windows, narrower set points for indoor climate than assumed, however, night cooling that was not assumed at the design stage. The performance monitoring shows that for an office building it can be rather complicated to evaluate whether the energy target is met or not.

Requirements for low energy use, good indoor climate and good visual comfort are not met for a glass office building without the added expense of careful planning and increased investment costs, especially for the facades, compared to a building with a traditional facade. Energy costs are not lower than that of a good traditional building. If low energy demand for heating and cooling is required, it can only with present glass facades be achieved by a further reduction in window area.

Acknowledgements

The performance monitoring and evaluation was funded by the Swedish National Board of Housing, Building and Planning and Midroc.

References

[1] Blomsterberg, Å.. *Glazed office building – Follow-up of energy, daylight and indoor climate for a glazed office building during pre-design and design in Malmö* (in Swedish). Client group for premises, Can be downloaded at: www.belok.se, 2007.

[2] Blomsterberg, Å.. *Performance monitoring and evaluation of energy and indoor climate, and environmental rating of a modern glazed office building in Malmö, Sjömannen 1* (in Swedish). WSP, 2011.

[3] Blomsterberg, Å.. *Air tightness in office buildings – Measurements and calculations* (in Swedish). SBUF, Can be downloaded at: www.sbuf.se, 2009.

[4] http://www.equa.co/ .

[5] Blomsterberg, Å.. *Possibilities with glazed office buildings in the Scandinavian countries – Energy and indoor climate* (in Swedish). Energi och ByggnadsDesign, Arkitektur och byggd miljö, Lund University, report EBD-R—08/20, Can be downloaded at: www.ebd.lth.se, 2008.

[6] Levin, P., Blomsterberg, Å, et al. *User input for energy calculations of offices – guidance* (in Swedish). Svebyprogrammet, Can be downloaded at: www.sveby.org, 2010.

[7] Persson, A., et al. *Improved energy statistics for premises – Step by step STIL (in Swedish). Report for year 1 – Inventory of offices and administrative buildings*. Swedish Energy Agency, 2006.

Design and Energy Performance of a Very Low Energy Building

N. Aste, M. Buzzetti, L.C. Tagliabue

Dept. BEST – Building Environment Science & Technologies - Politecnico di Milano

Abstract

Total energy consumption of office buildings has a relevant weight in Europe, and the trend shows a consistent growth in long term period. The reference values for energy consumption in this building sector is about 33 kWh/m^3 year for heating and an average value of 45 kWh/m^3 year for cooling. Other 16 kWh/m^3 year can be considered as additional electricity energy consumption used for equipments and artificial lighting. For new buildings, the minimum consumption required for heating amounts to 27 - 43 kWh/m^3. That range can be referred to a middle quality performance in current Italian energy labelling system (Class D). In addition to the energy certification required by the national regulation, nowadays in the real estate market the application of rating systems to assess the environmental quality of the buildings is taking place. LEED certification, for example, was recently introduced in the international real estate sector and was customized in Italy.

The case study is a “H” shape building, located in the middle suburb in the North-East of the city core of Milan. The office building is located in an area typified by the urban fabric of the 20th century. The building design integrates the energy issues using technologies to achieve a strong innovation in the architectural project.

Dynamic energy simulations were carried out during the design phase in order to optimize the energy performance of the H-Building. The results show that primary energy consumption for heating is about 6 kWh/m^3 year, and for cooling is about 5 kWh/m^3 year. The aim of the building is to obtain the label Class A in the regional regulation and an international LEED certification.

Nomenclature

CHP = Combined Heat & Power

GWHP = Ground Water Heat Pump

COP = Coefficient of performance

EER = Energy efficiency ratio

1. Introduction

Energy audit on office buildings in different climatic zones of the national territory [1] has identified the average values of total specific consumption referred to electricity and to primary energy for heating [2]. Considering the consumption data for each climate area with the percentage of location of office buildings it has been observed that the national average for heating consumption is about 80 kWh/m^2 year. The average specific fuel consumption amounts to 95 kWh/m^{2}year for the office buildings located in climatic zones D and E (72% of the total number of buildings). This value is calculated as net consumption without considering the electricity requirements for air treatment. For most of the buildings located in the northern part of the country and in other cold climate areas the average value amounts to 100 kWh/m^2 year [3].

The EPBD directive [4] imposes new buildings “nearly” zero energy in 2018 for public buildings and in 2020 for private buildings. Hence, it is important to underline how to obtain these results by improving the energy performance of building throughout exemplary projects situated in a consolidated built environment, as in Italians cities.

Rating system as LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), etc. cannot always guarantee high energy performance in buildings [5]. They can evaluate the strategies used for a predefined level of "sustainability" [6] that vary in comparison between different rating systems [7].

In this work, dynamic simulations are conducted to estimate the energy performance of the case study building. In such a way the energy evaluation of this building is approached in a more realistic way [8], [9]. The presented case is called H-Building, due to his shape. The office building was designed by an innovative approach and the energy experts and designers worked as a team from early stage of the project development. The building will be realized in near future consistently with economic constraints and authorization and it can be considered a leading project for commercial buildings in temperate climates [10], [11]. The architectural design project is realized by the Lisciandra Studio, Milan.

2. Description of the building

H-Building is placed in the north-east zone of Milan, Italy. It is destined to stand out from its surroundings while respecting a shared aesthetic. Its aim is to communicate with adjacent buildings and with the street's shape. With a large open courtyard as an entrance, its two rectangular wings are connected by a "non-wall" of glass, facilitating permeability between public and private spaces, in a fluid interplay of transparency, air and light. H-Building is a multi-storey building, for a total area of 10'000 m^2, characterized by fittings and technological systems of the very high standard, combining sophisticated materials and quality performance (Figure 1).

Figure 1 Views of the building.

The heated volume is equal to 38'858 m^3 and the relationship between the dispersing surface of the building and the heated gross volume (S/V ratio) is 0.3. Instead of realizing a continuous front on the street, the building is set back at the entrance, where the court acts as a central element of transition and stops between the entrance and adjacent urban environment. Building's functions are summarized in Table 1.

Table 1 Functions distribution.

Functions	**Units**	**Quantity**
Total offices and common areas	m^2	10'076
Total archives	m^2	1'214
Total covered car parking spaces	n.	204
Total covered motorbike parking spaces	n.	42

The H-Building project was supported by a complete study of the energy flows including a careful evaluation of the criteria of sustainability. The building will be LEED certified, having met the requirements relating to energy efficiency, materials and indoor environmental quality.

The relevant characteristics of environmental sustainability can be summarized as follow:

- orientation and shape of complex;
- high quality details using low-emissions materials;
- advanced technologies to improve energy saving;
- shading systems fixed on the facades completed by internal solar protection devices;
- high quality thermal insulation for transparent and opaque envelope;
- maximum use of natural light and efficient artificial lighting;
- natural ventilation combined with air treatment;
- high-efficiency heat pumps with heat recovery;
- sophisticated control system by BEMS (Building Energy Management Systems).

The whole area surrounding the building is planted with green shrubs and trees and during the summer shaded areas encourage the use of outdoors spaces. A special emphasis was assigned to open spaces design realizing three different compartments: the open courtyard of the walkways (A), the garden which faces the building (B) and the boundary garden (C) (Figure 2).

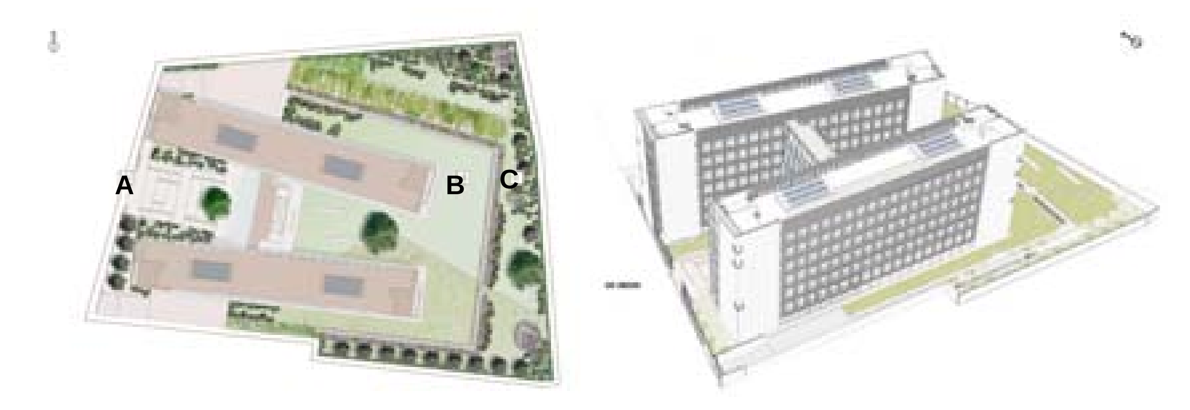


Figure 2 Roof plant and layout of the site.

All the technologies used in the H-Building project allow to reach high levels of thermal, visual, acoustic, hygrometric comfort for the users. At the same time, the use of such technologies provides cutting-edge performances which guarantees a healthy, green, eco-sustainable work environment. H-Building was designed with specific awareness to energy efficiency, taking into account the strategies which can be suggested to reach a “nearly” zero energy building as resumed in Figure 3.

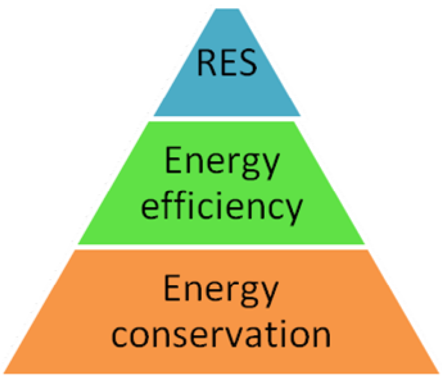
<table>
<tr><th>Approach</th><th>Strategies</th></tr>
<tr><td rowspan="3">
</td><td>• PV plant</td></tr>
<tr><td>• efficient HVAC systems
• GWHP</td></tr>
<tr><td>• shape and orientation
• insulation and mass of envelope
• shading systems
• use of daylighting</td></tr>
</table>

Figure 3 Role played by major design features of the building.

The strong commitment on energy savings is combined with the selection of materials to ensure quality of indoor environment. The holistic approach adopted in the building will lead to the achievement of LEED certification. The rating system includes different areas, in particular: sustainable location, water conservation, energy and atmosphere, resources and materials, indoor quality and innovation and design. H-Building energy performance falls into the local regulation Class A, that is primary energy for heating between 3 and 6 kWh/m^3 year [12, 13].

Figure 4 External and internal render of H-Building.

The comfort in the workplace is also realized through warm and cozy materials such as wood and stone and architectural details. Distribution elements as elevators, escalators and walkways are realized as transparent volumes bringing light into the building. Micro-perforated modular panels have been used in the office spaces. The ceiling is equipped with recessed luminaries ensuring high standard of illuminance on the work plan (500 lux).

The floating floor is made of modular panels of 34 mm laid on a support structure made of galvanized steel (total height of 20 cm). Maximum flexibility both in open space and in cellular offices and an efficient distribution of space is pursued by the total absence of internal columns. The curtain wall is made by aluminum transoms and mullions supporting wide glazed surfaces. In most of working hours the glazed facades provide natural light to the working spaces.

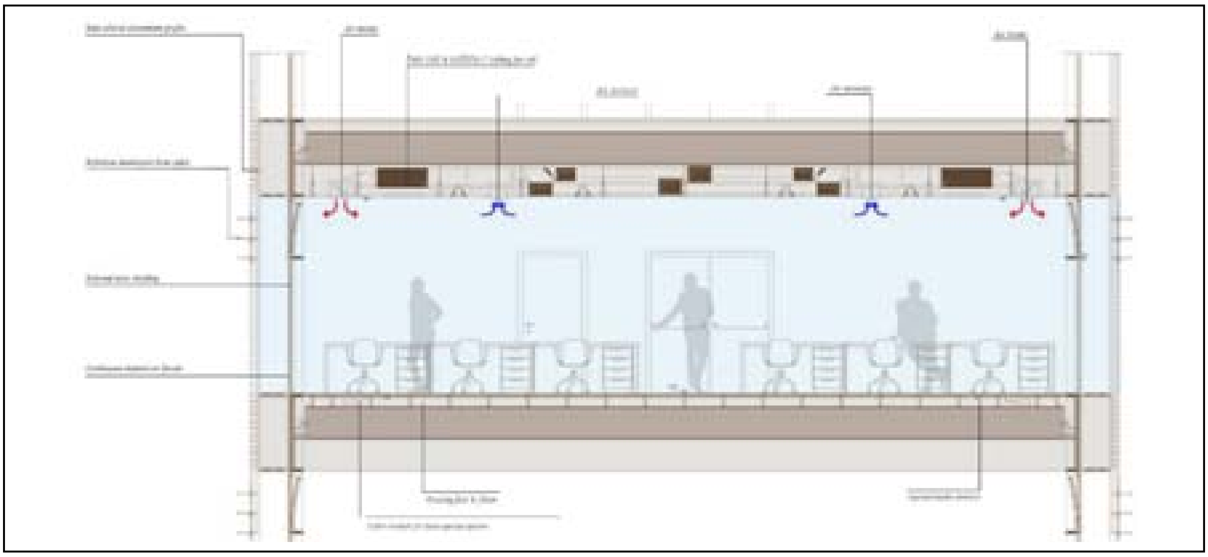


Figure 5 Cross section of standard floor.

Table 2 summarizes the main features of the building.

Table 2 Layers and thermal characteristics of H-Building envelope.

Opaque vertical envelope			
Definition	**Location**	**Characteristics**	**U [W/m^{2}K]**
External wall	Office facades	Coated steel 2 mm, 10 cm polyurethane, coated steel 2 mm	0.22

External wall	WC and stairs	Tile 1 cm, 25 cm concrete, expanded polystyrene 10 cm, air gap 2.5 cm, tiles1 cm	0.28
Internal wall	Between WC and stairs	Plaster 1.5 cm, 10 cm polystyrene foam, 12 cm brick, plaster 1.5 cm	0.24
Transparent vertical envelope			
Definition	**Location**	**Characteristics**	**U [W/m^{2}K]**
Double doors window	facade	2.72 x 3.00 m^2	1.30
Single door window	facade	1.35 x 3.13 m^2	1.30
Opaque horizontal envelope			
Definition	**Location**	**Characteristics**	**U [W/m^{2}K]**
Floor ceiling	Roof	Concrete 50 cm, 10 cm expanded polystyrene	0.27
Lower Floor	On stilts	Mortar 2 cm, 10 cm expanded polystyrene, concrete 50 cm	0.28

3. Technical systems

3.1 Thermal Plant

In the first design phase the HVAC plant was supposed to have a CHP system powered by natural gas combined with a GWHP system providing energy for space heating and cooling. Later analysis showed that just the GWHP was enough to fulfill the energy requirements of the building and the additional CHP will not improve, considering CH_4 cost, the overall economical performance of the whole system.

The terminal units located in the ceiling are fan coils. Each terminal unit can produce cool or heat independently of the other terminals, in order to obtain optimal microclimate conditions based on individual users' choice and the external weather conditions. The system can switch quite instantly between heating and cooling or vice versa, and can simultaneously provide heat to some rooms while cooling other areas.

In addition to the fan coils, a network of pipes is provided to ensure an adequate air exchange inside the rooms. The minimum flow rate considered amounts to 40 m^3/h for each person and/or air change rate of 1.5 V/h, the choice will be based on the occupational profile of each room by adopting the more restrictive conditions.

The air flow is controlled by the air handling units located on the roof. These air handling units have the function to supply properly treated and filtered air inside the rooms as well as recover a large proportion of the heat in the exhaust air. Part of the air is extracted from the toilet through exhaust towers placed on the roof and expelled directly into the atmosphere.

The control of the HVAC system is carried out locally for individual fan coil units: manual control for each terminal or in a coordinated way through zone controllers with a central supervision. In this way it is also possible to control the operating parameters of air handling units to guarantee a high comfort level. It is expected to divide each floor into at least two zones, with independent control strategy.

HVAC system uses hot and cold water generated by a ground source heat pump (GWHP) system based on ground coupled heat exchangers.

A metering system for each unit has been designed to measure the consumption of fluids (hot and cold) for subsequent reporting and accounting.

Indoor and outdoor design conditions are shown in Table 3.

Table 3 Outdoor and indoor design conditions.

Outdoor design conditions	Winter design temperature and relative humidity	-5 °C; UR 90%
	Summer design temperature and relative	32 °C; UR 50%

	humidity	
	Intermittent function type with switched off at night	
	Time to achieve 100% efficiency	2 hours
Indoor design conditions	Fresh air supply	40 m^3/h person
	Winter indoor temperature	20 °C (+ 2 ° C)
	Summer indoor temperature	26 °C (± 2 °C)
	Inside humidity	50% (± 10%)
	Forced air extraction for toilets	6 V/h
	Air velocity within the lower tubes	• 4 m/s
	Air velocity inside rooms	<0.15 m/s

3.2 Electrical System

Each office is powered by its own energy meter and the electrical connection is low voltage (400 volts), three phases with neutral type, frequency of 50 Hertz and TT system. In each floor, an electric board will be installed which contains the electrical power circuits for the following utilities:

- normal lighting and security-employment;
- power points for toilets and corridors;
- power points for electric utilities;
- power supply fan coil.

3.3 Energy Power System Security Condominium

Emergency energy is produced to serve the centralized emergency lighting of the staircase, the entrance lobby and the floor landings. During power strikes or blackouts the emergency energy is produced by a UPS generator. A connection with the generators is planned to be installed.

3.4 Building Management System

The building is equipped with an automation control to ensure the monitoring and control of the functions i.e. lighting, blinds, heating, ventilation, air conditioning and the management of load, control and alarm. The system provides a serial data transfer between the components connected to the bus. It works like a flexible, compatible and low cost to support the above mentioned applications. The bus system is usually implemented as a decentralized system but, if necessary, can be implemented as a centralized system. The decentralized system is implemented between the units (transmitters or receivers) which communicate directly with each other without resorting to hierarchy or network monitoring systems.

3.5 Photovoltaic System

The rooftop is equipped by a 120 kW_p photovoltaic grid connected system to produce electricity for the common spaces and centralized high-tech alarms. The system supplies about 8% of the total electrical energy requirements. The photovoltaic system consists in crystalline modules and appropriate electrical devices.

4. Methods

Energy assessment was performed under dynamic conditions in order to guide and support scientifically design choices for the building. A virtual model was created with OpenStudio BEST software in order to perform dynamic calculations (Figure 6). The amounts of energy demand for heating and cooling was calculated.

The OpenStudio BEST software used in the present work was developed from a well known open-source plug-ins distributed by the National Renewable Energy Laboratory (NREL) called OpenStudio. The OpenStudio BEST plug-in uses the Google SktechUp graphic interface and the energy simulation tool Energy Plus, allowing the user to perform energy calculations using a dedicated toolbar. In fact OpenStudio BEST tool is a plug-in associated with Google SketchUp 8 which runs the calculation engine EnergyPlus 7.0 [14, 15, 16], in order to carry out energy simulations in dynamic conditions. Therefore, it combines the easy and intuitiveness of SketchUp modeling and the computational power of EnergyPlus. The combination of these two software permits to execute building dynamic simulation in the most sophisticated designs. It is possible to create computational models in a more intuitive way and to estimate energy demands and therefore energy consumption of buildings.

The tool is used for advanced energy analysis. The weather file used for simulation records hourly data of a typical meteorological year (TMY) for the reference location (Milan). Taking into consideration the thermal plant designed, primary energy consumption was calculated to supply energy to the total volume in summer and winter periods. Results were compared to the regional energy regulations [17].

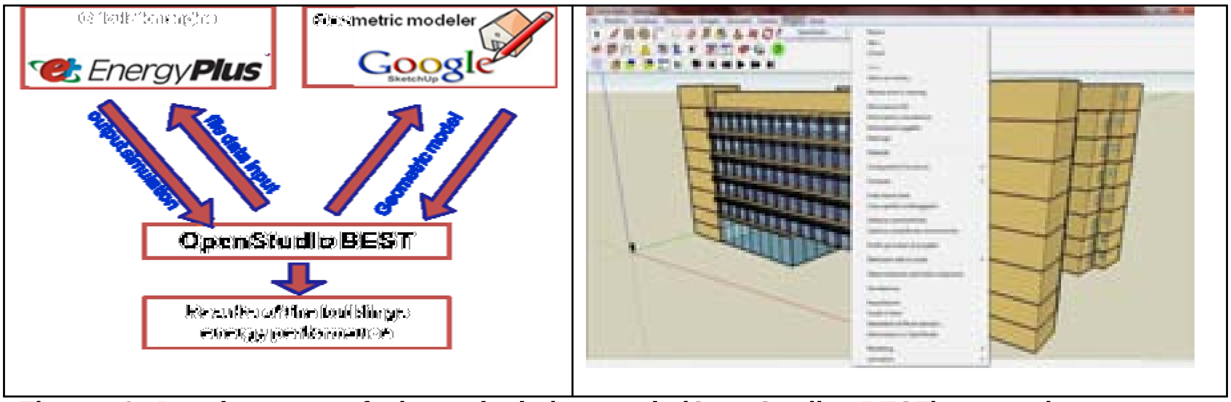


Figure 6 Development of the calculation tool (OpenStudio BEST) to estimate energy performance; on the left; Google SketchUp and the Open Studio Plugin dropdown menu on the right.

5. The building model description

The following section contains a description of the input data used for the energy simulation.

5.1 The building

The energy model is a simplification of the real building. It is realized with 80 thermal zones; 38 zones are neither heated or cooled (i.e. stairwells and accessories rooms) and 42 are air conditioned zones (i.e. office areas, open space and restrooms). In Figure 7 are shown the model made by Google SketchUp 8 and the screenshot of the simulation software used (Energy Plus v.7).

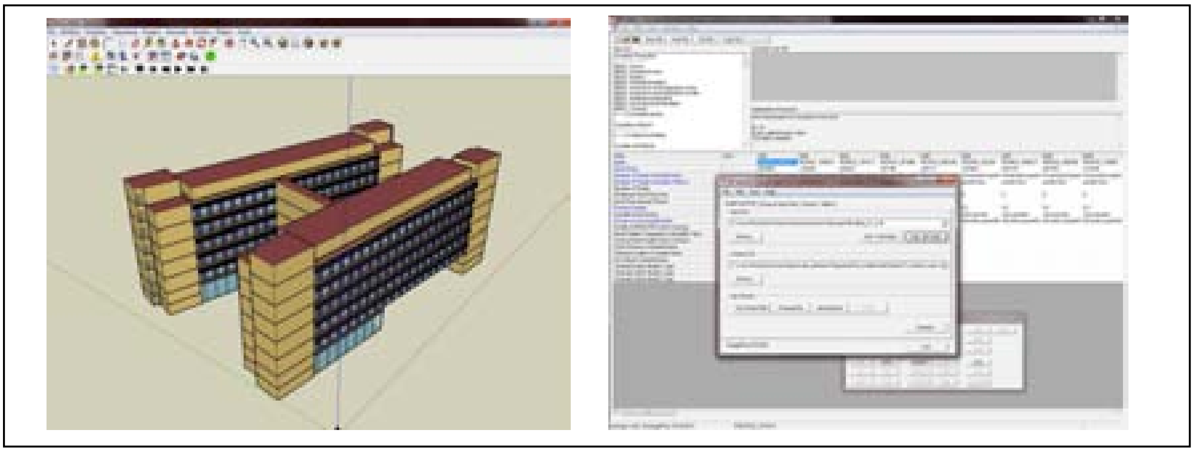


Figure 7 Building energy simulation model and screen of Energy Plus.

The analysis assumes standard parameters adopted according to the use of the building; data are reported in Table 4.

The ventilation and air infiltration rate amounts to 1.5 V/h for both heating and cooling as specified in the actual regional regulation of Lombardy for office buildings. Another important design data is the estimation of internal heat gains according to the presence of people, household electrical appliances and lighting systems inside the building. This value is estimated on the basis of real data analyzed on existing office building and can be assumed about 13 W/m^2.

Heating load analysis due to people was conducted considering conservative reference values: a maximum of 126 W/user is assumed in the offices during working hours. The period of occupation is assumed from 8:00 to 20:00 during weekdays. No people is considered in the office during the weekends.

Table 4 Description of simulation parameters.

Simulation parameter	Value
Internal gain (equipment, illumination)	13 W/m^2 during winter and summer period
Ventilation and infiltration rate	1.5 V/h during winter and summer period
Solar control	Yes: use shading when the incident solar radiation is equal to 300 W/m^2
Heating period Set point for all day	October 15 - April 14 20°C and 50% RH
Cooling period Set point for all day	January 1 - December 31 26°C and 50% RH
Occupancy	From 8:00 to 20:00 for weekdays of all year
Activity level	1.2 met (126 W/occupant)
Occupant's density	0.12 occupant/m^2

5.2 HVAC system

The project assumes the use of a HVAC system to serve the complex with one ground source water-water heat pump integrated with fan coil system providing heating in winter as well as cooling during summer period. A dehumidification system for humidity control in summer period is also to be installed. Primary energy consumption of the building has been calculated. The value of COP (for heating) and EER (for cooling) considered are equal to 4.3 and 5.4 respectively. These values are based on the products available in the market nowadays.

In the energy consumption analysis, the efficiencies of auxiliary systems e.g. distribution (pipes and tubes for fluid flows), emission (radiant floors and fans) and control systems (thermostat controls and devices) are estimated. The final value of overall efficiency of auxiliary systems is about 94%.

The total electricity used by the auxiliary systems during winter and summer is, respectively, about 15% of total consumption of each one. The photovoltaic system, installed on the rooftop produces an average of 118'000 kWh/year. This amount of electricity is used to cover the energy demand of the building's air conditioning system.

6. Results and discussion

A number of strategies are implemented to achieve the goal of a very low energy building. Table 4 shows the characteristics of the systems used in the building to control energy demand. Thermal plant and envelope characteristics are resumed in Table 4.

Table 4 Energy saving measures implemented in H-Building, envelope and plants.

ENVELOPE TECHNOLOGY			
Transparent envelope			
Strategy	**Objectives**	**Components characteristics**	**Technical parameters**

Insulation glass facade	Thermal resistance, light transmission, solar gain	Alluminum frame with thermal break, insulation glass	Surface 2.72x3.00 m^2; Thermal transmittance 1.30 W/m^2K
Solar control devices	Optimize daylighting in the open space, heat load reduction in summer period	Blinds to deflect light, mobile systems in the lower part of the windows	3 fixed aluminum blinds, and mobile shading devices
Opaque envelope			
Strategy	**Objectives**	**Components characteristics**	**Technical parameters**
External wall (thermo-wall)	Thermal insulation	Steel/polyurethane sandwich	Polyurethane 10 cm, λ = 0.022 W/mK
Floor ceiling and lower floor	Thermal insulation	Use of expanded polystyrene foam, polystyrene XL400 G	Polystyrene 10 cm e 8 cm; λ = 0.031 W/mK
PLANT TECHNOLOGIES			
Strategy	**Objectives**	**Components characteristics**	**Technical parameters**
PV plant on the roof	Solar energy production	4 sections, polycrystalline modules 200 W_p each	Surface 1'000 m^2 tilt angle 10° azimut angle 0°; Peak power 120 kW
HVAC	Supply fresh air and heat recovery	Air handling and heat recovery from air exhausted	2 HVAC units, 14'000 m^3 for the replacement of 1.5 V/h, 52-53% heat recovery
GWHP	Production of hot and cold fluids	GWHP located in the basement; the fluid used is groundwater drawn from a special pit	Nominal power 490 kW; Electrical power consumption 116 kW; COP 4.3; EER 5.4

The conversion factor between electricity and primary energy is equal to 2.17 kWh/kWh_e [18]. This value corresponds to the typical fuel mix used by the national electrical energy production system.

Conditioning systems and photovoltaic system will be managed by the same owner. The electricity demand for the equipment and artificial lighting is referred and paid by each individual tenant. This electricity consumption can be estimated about 20 kWh/m^2 years for lighting and 45 kWh/m^2 years for equipments.

Comparing the average consumption of the office buildings with H-Building, the difference is about of 83% in winter and 85% in summer. An estimate of energy demand results a decrease of 40% during winter and about 70% in summer. The photovoltaic system, instead, contribute to an average reduction in final consumption of 25% in winter and 50% in summer.

Simulations results are described below.

6.1 Energy demand

The estimated annual heating demand is about 14 kWh/m^3 year; the energy demand for cooling is estimated as 17 kWh/m^3 year. The cooling demand includes the sensible as well as the latent energy demand.

Figure 8 shows the results of the simulations, on a monthly basis. Winter and summer energy demands are resumed in the graph.

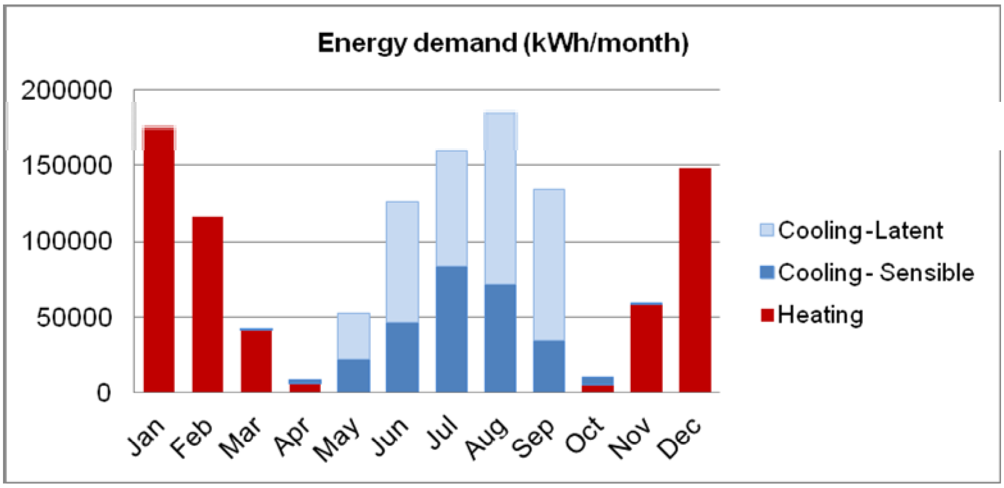


Figure 8 Monthly energy building demand (kWh/month).

6.2 Primary energy consumption

Considering the thermal plant efficiency as described in section 5.2, the estimated value of annual heating consumption is about 5.8 kWh/m^3 year, the energy consumption for cooling is expected to be 5.1 kWh/m^3 year. Figure 9 shows the monthly energy consumption results calculated subtracting photovoltaic energy production to the electrical energy consumption of traditional sources for heating and cooling.

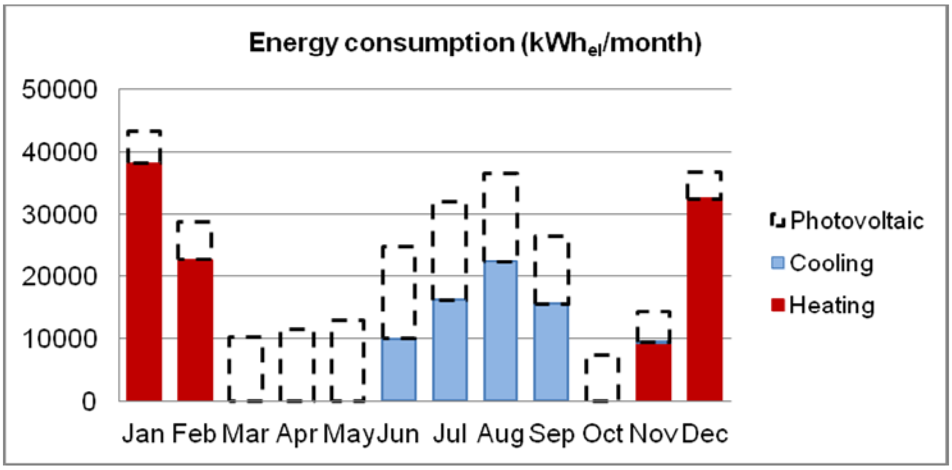


Figure 7 Monthly energy consumption fort H-Building (kWh$_{el}$/month).

7. Conclusions

The present work shows how an integrated design of the envelope associated with an appropriate HVAC system can optimize energy consumption. The design process to pursue energy saving requires a continuous interaction between the different design team members and energy experts. The optimization of the system constituted by building and plant allows achieving very high quality in term of energy performance and comfort level.

Nowadays, a dynamic energy analysis for office buildings is required to optimize the building energy performance. Therefore, dynamic calculation software is the tool that permits to describe the thermal behavior of the building closer to the real running conditions. Unfortunately, dynamic simulations are still not easy to be performed. Therefore, the advantage of OpenStudio BEST consists in the possibility of using a friendly graphic interface as SketchUp for modeling, and the most technological advanced energy calculation engine of EnergyPlus to reproduce the energy consumption of the designed building.

Acknowledgments

The authors would like to thank Arch. Umberto Beneventano for the kind availability and for all architectural materials. Special thanks go to Ing. Mario Maistrello for useful discussions and valuable insights while carrying out the present work.

References

[1] ENEA, (2009). *Caratterizzazione dei consumi energetici nazionali delle strutture ad uso ufficio*, www.enea.it/enea_paese.

[2] ENEA, (2009). *Rapporto Energia e Ambiente – Analisi e Scenari 2008*, http://www.enea.it/it/produzione-scientifica/rapporto-energia-e-ambiente-1.

[3] ENEA, (2010). *Rapporto Energia e Ambiente – Analisi e Scenari 2009*, http://www.enea.it/it/produzione-scientifica/rapporto-energia-e-ambiente-1.

[4] European Commission. Commission Directive EPBD recast (2010), Directive 2010/31/EU 19 May 2010, *on energy performance in buildings* (recast), Official Journal of the European Union.

[5] Scofield J. H., *Do LEED-certified buildings save energy? Not really … ,* Energy and Buildings 41 (2009) 1386–1390.

[6] Salman A., Wade A. C., Darren O., Irtishad A., Building information modeling for sustainable design and LEED® rating analysis, Automation in Construction 20 (2011) 217–224.

[7] Binh K. N., Hasim A., *Comparative review of five sustainable rating systems,* Procedia Engineering 21 (2011) 376–386.

[8] Poirazis H., Blomsterberg A., Wall M., *Energy simulations for glazed office buildings in Sweden,* Energy and Buildings 40 (2008) 1161–1170.

[9] Pan Y., Yin R., Huang Z., *Energy modeling of two office buildings with data center for green building design,* Energy and Buildings 40 (2008) 1145–1152.

[10] UNI 10349 (1994). *Riscaldamento e Raffrescamento degli Edifici, Dati Climatici*.

[11] DPR 412/93, *Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia*, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n. 10.

[12] Decreto Legislativo 19 Agosto 2005, No.192. *Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia*.

[13] Decreto Legislativo 29 dicembre 2006, No.311. *Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, No. 192, recante attuazione della direttiva 2002/91/CE. relativa al rendimento energetico nell'edilizia*.

[14] DOE (2008), *U.S. Department of Energy Building Technologies Program (BTP),* EnergyPlus Software Version 3.1.0, Washington.

[15] D.B. Crawley, L.K. Lawrie, C.O. Pedersen, F.C. Winkelmann, M.J. Witte and R.K. Strand et al. (2004), *EnergyPlus: an update,* Proceedings of international symposium of simBuild August 4–6, International Building Performance Simulation Association, Boulder (CO, USA).

[16] D. Crawley, L. Lawrie, C. Pedersen, R. Strand, R. Liesen, F. Winkelmann, F. Buhl, J. Huang, E. Erdem, D. Fisher, M. Witte and J. Glazer (2001), EneryPlus: creating a new-generation building energy simulation program, Energy and Buildings 33, pp. 319–331.

[17] Delibera Giunta Regionale 22 Dicembre 2008, No.8/8745. *Determinazioni in merito alle disposizioni per l'efficienza energetica in edilizia e par la certificazione energetica degli edifici*.

[18] Delibera EEN 3/08 (2008), *Aggiornamento del fattore di conversione dei kWh in tonnellate equivalenti di petrolio connesso al meccanismo dei titoli di efficienza energetica*, www.autorità.energia.it.

Optimal transparent percentage in façade modules for office buildings in a central Europe climate: a case study in Frankfurt.

Francesco Goia[1,2,3], Matthias Haase[2,3], Marco Perino[1]

[1] TEBE Research Group, Deptartment of Energy, Politecnico di Torino, Italy.

[2] The Research Centre on Zero Emission Buildings, Faculty of Architecture and Fine Art, Norwegian University of Science and Technology, Norway.

[3] SINTEF Building and Infrastructure, Norway.

Abstract

The building enclosure plays a relevant role in the management of the energy flows in buildings and in the exploitation of the solar energy at building scale. An optimal transparent percentage of the façade can contribute to reduce the total energy demand of the building. Traditionally, the search for the optimal transparent percentage of the façade is obtained by analyzing the heating demand and/or the cooling demand only, while the implication of the façade configuration on the energy demand for artificial lighting is often not considered, especially during the first stage of the design process.

A global approach (i.e. including heating, cooling and artificial lighting energy demand) is instead necessary to reduce the total energy need of the building. When considering the total energy use in building, the optimization of a façade configuration becomes not straightforward, because non-linear relationships often occur. The paper presents a methodology and the results of the search of the optimal transparent percentage of a façade module for office buildings. The investigation is carried out for the four main orientations, on three "average" office buildings (with different surface-area-to-volume ratio), and with different HVAC system's efficiency, located in Frankfurt.

The results show for a rectangular office building with cell offices along the facades that the optimal transparent percentage of the façade, regardless of the orientations and the surface-area-to-volume ratio, is achieved in a new office building with low energy windows when the transparent component of the façade module is between 35% and 45% of the total façade module surface. The north-exposed façade is the one that presents the highest difference between the "optimal configuration" and the worst one, while the south-exposed façade is the one which suffers less in case of the "worst" configuration.

Introduction

It is a well-established concept that the façade can play a crucial role in the management of the energy flows and can contribute to achieve energy efficiency in building. In fact, the energy exchanges between the two systems take place through this element, that is the border between the indoor and the outdoor environment. This vision is particularly relevant in residential buildings, where internal loads are usually quite low and HVAC systems are usually simpler; however, the same concept is also applicable to commercial buildings. The conventional approach focuses on the "negative" aspects related to the role of the façade: when considering the heating energy demand, the façade, together with the other building enclosure surfaces, is responsible for the heat loss. In this perspective, the transparent elements of the façade are the weakest spot of the construction. However, it is now also common to consider the "positive" feature of the transparent part of the façade, i.e. the ability to exploit the solar gain to reduce the heating energy need, and the possibility offered by the façade to provide daylighting for the indoor environment. Looking at the façade from a total energy perspective – i.e. heating demand, cooling demand and energy for lighting –, and especially in the frame of commercial buildings, the façade can be therefore considered the first and basic technology for solar energy exploitation the building scale. While the opaque part can control (and possible reduce to the minimum extent) the heat losses, the transparent part is asked to maximize (in winter time) or minimize (during the summer), thank to dynamic fenestration systems (i.e. shading devices), the solar heat gain; furthermore, it is also asked to provide the amount light to reduce to the minimum extent the energy need for artificial lighting. The main way through which the façade configuration affects the total energy efficiency of the building is therefore the balance between the opaque and the transparent elements.

The analysis of the balance between the transparent and the opaque part of a façade module can provide useful information for future design of building that present low energy need, as required by the recent EU directive (EPBD recast) [1]. In fact, façade modules are gaining popularity, especially in present-day commercial buildings, and are seen as potential, market-available technology, to increase energy efficiency in buildings.

Conventionally, the optimization[1] of a façade configuration (transparent-to-opaque ratio) is carried out by mainly considering the heating and cooling energy demand of the building. Therefore, only the balance between the heat losses and the heat gains during the cold season is taken into account. The implication of the façade configuration on the energy consumption due to artificial lighting is instead very often neglected. However, when considering the total energy use in building, the optimization of a façade configuration must take into account also the energy for lighting, and cannot be based only on considerations derived from the analysis of the heating (and cooling) energy demand. This is because the energy demand related to the lighting is a crucial term of the total energy balance. Furthermore, when heating, cooling and lighting energy demands are considered, innumerable variables are involved and non-linear relationships often are registered. Even though many variables are kept constant and the only ratio between transparent and opaque surface is investigated, there are many other inter-actions that can make the process quite complex and the outcomes of the investigation not always foreseeable.

The aim of this paper is to demonstrate that the optimization of a façade module, once the minimal requirements on thermal and visual comfort are met, requires the contemporary evaluation of all the energy demands that can be directly affected by the façade configuration itself – i.e. energy demand for heating, cooling and lighting. The paper investigates a hypothetical, single skin façade module, realized with market-available, state-of-the-art technologies. A methodology to assess the optimal configuration of the façade module is then presented. It is aimed at giving practical information to façade manufacturers and practitioners about the “average” configuration of a façade for an “average” office building in a central Europe climate. Of course, the actual optimal configuration depends on the exact configuration of the office building (e.g. location, orientations, internal loads, occupancy), but this study can provide a rule-of-thumb that can be used during the preliminary design stage, as well as highlight some aspects that must be taken into account during the detailed design phase.

Method

Façade module technology

The façade module is a single skin façade technology, 3.7 m width and 3.4 m height, and it is realized with market-available technologies. The façade module is composed by two surfaces: a transparent part and an opaque part. The transparent surface is made of a triple glazing with low-e coatings and integrated solar shading devices – i.e. a highly-reflective external venetian blind system. The U-value of the glazing is 0.7 W m^{-2} K^{-1} and the Solar Heat Gain Coefficient (SHGC) is 0.46. The visible transmittance is 0.53. The opaque part is realized with a sandwich panel, made with 0.025 m thick Vacuum Insulation Panels, a 0.12 m thick rockwool insulation layer and some plasterboard layers. The outer surface of the opaque surface is made of a metal panel. The U-value of the opaque sandwich is 0.15 W m^{-2} K^{-1}. The façade module presents also a thermal break aluminum frame with U-value of 1 W m^{-2} K^{-1}. The U-value of the roof and floor of the building is 0.12 W m^{-2} K^{-1}.

---

[1] In this paper, the term “optimal configuration” means the transparent-to-opaque ratio that minimizes the total energy demand (primary energy) of the building. In other words, the optimization concerns exclusively the transparent-to-opaque ratio, while all the other variables (e.g. the materials of the façade modules and the performance of the subcomponents) are kept constant.

Five different transparent-to-opaque ratios were investigated for the façade module during the search for the optimal configuration: from a transparent surface of 20% of the façade module area (equivalent to ca 2.5 m^2) to up to a transparent surface of 80% of the façade module area (equivalent to ca 10.0 m^2). The surface of the façade module that is not transparent is made of both the frame and the opaque sandwich panel – the frame is around 10% of the total façade module area.

Office building specifications and data processing

The optimal configuration of the façade module is searched for an “average” office building, located in Frankfurt – temperate-oceanic climate, Cfb according to Köppen climate classification [2]. Additionally, in order to test the stability of the solution with respect to the building shape, three different office buildings, characterized by different surface-over-volume ratios (SA/V), were simulated. The SA/V employed were: 0.20, 0.25 (reference) and 0.30 m^{-1}. The three buildings share the same layout – i.e. a central corridor with cell offices on both the sides of the corridor; building services, staircase and lifts at the two ends of the corridors, cf. Fig. 1a. The plan concept of the building is derived by an “average” office building developed in the frame of the IEA Annex 27 activity [3]. The office buildings have a concrete structure with concrete slabs and lightweight interior partitions, an atrium area at ground level and an underground level that is not heated. Details on the geometry of three buildings are given in Table 1. Specifications of the building services and settings are given in Table 2; the internal loads and lighting-related data are illustrated in Table 3.

After the simulations were performed, the building was virtually “divided”, along the ax of the central corridor, in two volumes (half of the total volume each), and each of the two volumes is associated to a façade orientation (cf. Fig 1b-1c). Since the building is considerably smaller in width that in length, the building presents two main façades, i.e. north façade and south façade, if the main corridor is aligned along the ax east-west, or east façade and west façade if the corridor is aligned along the ax north-south. Therefore, during the data post-process phase, each building only presents two façades: south and north façades if L-dimension of the building is aligned to the W-E ax (cf. Fig 1b), or east and west façades if L-dimension of the building is aligned to the S-N ax (cf. Fig. 1c). Therefore, the energy demand associated to a single orientation takes also into account the energy demand associated to areas that do not necessarily present this orientation[2]. In this way, the façade orientation is representative of the half of the building facing that orientation.

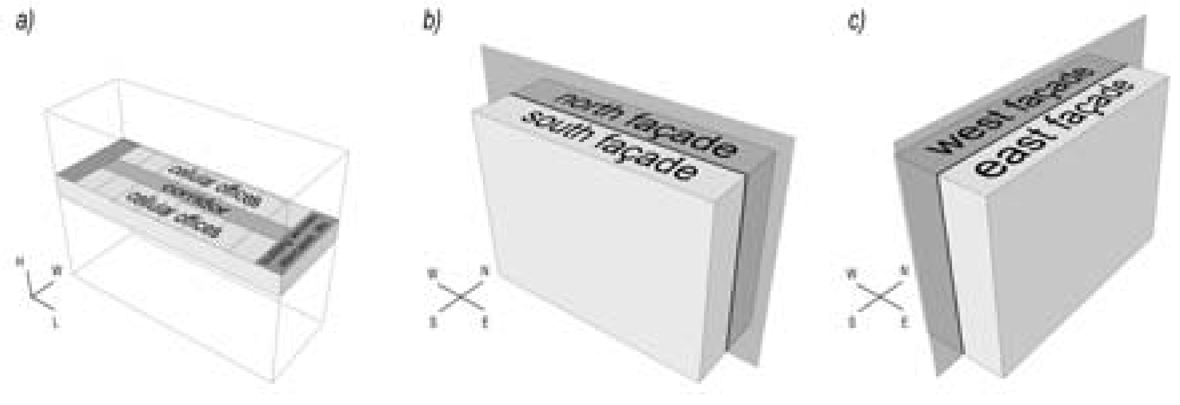


Figure 1. a) Plane concept of the office building. b) Subdivision of the volume building in two volumes associated to two main orientations

[2] E.g. In a building where the corridor is aligned along the ax east-west, the south orientation also takes into account volumes that have a west and east orientations (where the building services, lifts and staircases are). The north orientation follows the same rule.

Table 1. Dimensions of the three office buildings

SA/V	Length (L)	Width (W)	Height (H)
[m^{-1}]	[m]	[m]	[m]
0.20	53.3	14.4	90.1
0.25	*45.9*	*14.4*	*28.9*
0.30	38.5	14.4	18.7

Table 2. HVAC system specifications

	Temperature set-point (heating/cooling)		HVAC specification				
	Summer	Winter	Mechanical ventilation	Heat Recovery Efficiency	Specific Fan Power	SCOP heating	SCOP cooling
	[°C]	[°C]	[$l\ s^{-1}\ m^{-2}$]	[-]	[$kJ\ m^{-3}$]	[-]	[-]
Occupancy ***Mon – Fri 8am – 5pm***	20 / 24	23 / 26	1.42	0.80	1.5	2.6	3.8
Non occupancy	17 / 27	20 / 29	0.70	0.80	1.5	2.6	3.8

Table 3. Internal loads and artificial light

	Internal loads		Lighting	
	People [$W\ m^{-2}$]	Equipment [$W\ m^{-2}$]	Installed power [$W\ m^{-2}$]	Illuminance set-point [lux]
Occupancy ***Mon – Fri 8am – 5pm***	5.0	10.0	7.5	500
Non occupancy	0.0	1.0	7.5	0

Optimization procedure and simulations

The aim of the search was to find the optimal transparent-to-opaque ratio of the façade module that minimizes (Eq. 1) the total energy demand of the building E_{tot} (Eq. 2), where E_h is the heating primary energy demand, E_c is the cooling primary energy demand, and E_l is the lighting primary energy demand, on a yearly base. The conversion factor for electrical energy to primary energy was 2.5.

$$f : \min\{E_{tot}\} \quad \text{(Eq. 1)}$$

$$E_{tot} = E_h + E_c + E_l \ \ [kWh_{pe}\ m^{-2}\ y^{-1}] \text{ (Eq. 2)}$$

However, since the transparent part incorporates a solar shading system, an additional degree of freedom appears and complexity arises. In fact, since the solar shading device introduces a certain degree of dynamism to the façade module, a preliminary analysis on the influence of this system of the final result was needed.

In particular, it was necessary to identify the best strategy for the activation of the solar shading device. The choice of the strategy has a considerable influence on the final result. After some preliminary investigations, that are not reported here for the sake of brevity, the following strategy was adopted: the solar shading devices were activated if the zone cooling rate in the previous time-step were non-zero and if the solar radiation incident on the window exceeded a certain set-point value. The determination of the optimal set-point value (i.e. the set-point value that determines the lowest total energy demand) was not straightforward. This occurs because low set-point values may reduce the cooling energy demand, but increase the lighting energy demand and the heating energy demand, while high set-point values can produce the opposite effect. Thus, the search for the best set-point value becomes an optimization procedure itself. This procedure must be repeated for each orientation and for each transparent percentage, since different orientation and transparent percentage may have different optimal set-point values for the activation of the solar shading devices.

To perform this task, it was necessary to analyze one by one the orientations, and to test different transparent-to-opaque ratios for the same orientation. Therefore, during this round, the façade module (with a certain percentage of transparent surface) was adopted only on the orientation under investigation, while the opposite orientation was made of a fully opaque wall. The simulated building presented a SA/V = 0.25 m^{-1}. For each transparent percentage (20%, 35%, 50%, 65% and 80%), different set-point values for the activation of the solar shading system were tested: 100 Wm^{-2}, 200 Wm^{-2}, 300 Wm^{-2}, and 400 Wm^{-2}. A total of 20 combinations were therefore performed in order to determine the optimal set-point value, for each orientation and each transparent percentage.

Once the optimal activation flux for each transparent percentage and for each orientation was found, a second round of simulations was then performed. During this second round, 25 possible combinations where investigated for each building and couple of orientation, by combining the 5 different transparent-to-opaque ratios on the two opposite façades. During this round, the different transparent-to-opaque ratios adopted the optimized set-point values for the solar shading activation previously determined.

The integrated thermal and daylight simulations were carried out using the *EnergyPlus* software, performing calculations on hourly basis for the entire year. The coupling between the thermal model and the daylight model is based on the evaluation of the daylight factors. A daylighting calculation is performed each heat-balance time-step when the sun is up. The electric lighting control system (a continuous dimming control was applied) is simulated to determine the lighting energy needed to make up the difference between the daylighting illuminance level and the design illuminance set-point. Finally, the zone lighting electric reduction factor is passed to the thermal calculation, which uses this factor to reduce the heat gain from lights [4].

Reliability analyses

In order to assess the reliability of the achieved result (i.e. the optimal configuration of the façade module), two further investigations were performed: the stability of the results was tested against different building shapes (SA/V parameter where used); the stability was also tested against different HVAC systems that presented higher or lower efficiencies.

Results

Optimal set-point value for the activation of the solar shading device

In Table 4, the optimal set-point values for the activation of the solar shading system, for each orientation and transparent percentage, are presented. In Figure 2 and 3, the extra energy demands caused by non optimal set-point values are plotted. When the extra energy demand is 0, the optimal set-point value is reached.

As mentioned, the activation flux of the shading devices that optimizes the performance of the façade depends on the dimension of the glazed part and on the orientation. The set-point value decreases as the transparent percentage increases, for a south-exposed façade (Fig. 2a). In the case of a 20% glazed façade module, 400 Wm^{-2} is the solar heat flux that minimizes the total energy demand. On the contrary, in the case of a façade module with a transparent surface of 80% of the total surface, 100 Wm^{-2} is the best set-point value for activating the solar shading system. Intermediated glazed percentages require intermediated activation fluxes. The highest deviation between the optimal set-point value and the worse set-point value is achieved in the case of a 80% glazed façade module with a set-point value of 400 W m^{-2} – 6% more energy than in the case of the optimal activation heat flux.

Solar shading devices should not be placed on a north-exposed façade (cf. Fig. 2b), since the lowest total energy demand is achieved with high solar heat flux – i.e. solar heat flux higher then 400 W m^{-2}, which almost never occurs on a north-exposed façade. A low set-point value (e.g. 100 Wm^{-2}) reduces the ability to exploit solar energy (mainly for lighting purpose) and increases the total energy demand of about 5-7%.

Table 4. Optimal set-point values for the activation of the solar shading device

		Façade orientation			
		South *[Wm^{-2}]*	North *[Wm^{-2}]*	West *[Wm^{-2}]*	East *[Wm^{-2}]*
Transparent percentage of the façade module	20%	400	(400)	400	400
	35%	200	(400)	300	300
	50%	200	(400)	200	200
	65%	100	(400)	200	200
	80%	100	(400)	200	200

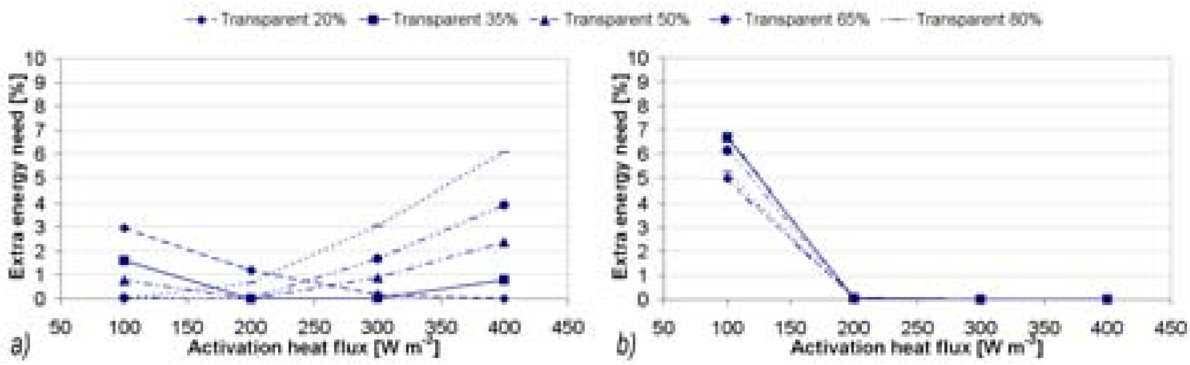


Figure 2. Extra energy demand determined by non-optimal set-point values for the activation of solar shading devices, for different transparent-to-opaque ratios: a) south-oriented façade; b) north-oriented façade

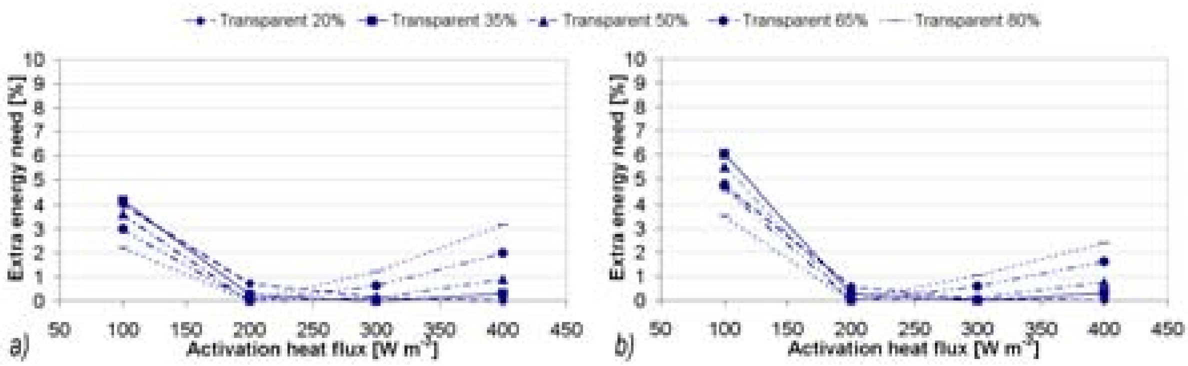


Figure 3. Extra energy demand determined by non-optimal set-point values for the activation of solar shading devices, for different transparent-to-opaque ratios: a) west-oriented façade; b) east-oriented façade

In the case of a west-exposed façade (Fig. 3a), the optimal set-point value lies usually in the range 200-300 Wm^{-2}. The two extremes (100 and 400 Wm^{-2}) determine a higher total energy demand. The only façade module's configuration which requires a different set-point value (400 Wm^{-2}) is the façade module characterized by the lowest transparent percentage (20%). A "wrong" set-point value may cause an increase in the total energy demand of about 3-4 %. An east-exposed façade (Fig. 3b) shows a similar behaviour to the one of a west-exposed façade: for almost all the ratios, the optimal set-point value stands in the range 200-300 Wm^{-2}. The lowest set-point value (100 Wm^{-2}) is always the less efficient, regardless the transparent-to-opaque ratio. For low transparent percentage (20%), the most efficient activation flux is again 400 Wm^{-2}. A non-optimal set-point value can lead to an increase of the total energy demand of about 4-6%.

Optimal configuration of the façade module

After the optimal set-point value of the shading devices was determined, two buildings having SA/V = 0.25 m^{-1} were simulated: one with the two main façades facing the south and the north (cf. Fig 1b); one with the two main façades facing the west and the east (cf. Fig. 1c). Therefore, two façades were analyzed by means of the same set of simulations[3]. 25 simulations for each building were then necessary. This is given by the combination of 5 different transparent surface percentages (20%, 35%, 50%, 65% and 80%) for the front façade, and the same 5 different transparent surface percentages for the back façade. This also determines that, for each transparent percentage analyzed on the front façade, five different E_{tot} were obtained, depending on the configuration of the back façade – and the other way round.

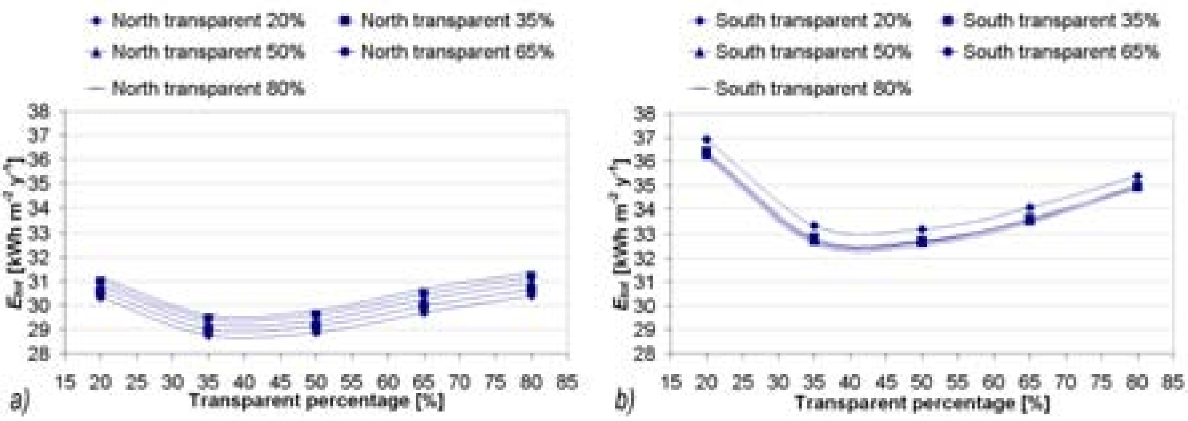


Figure 4. a) Total energy demand E_{tot} for a south-oriented façade module. b) Total energy demand E_{tot} for a north-oriented façade module. SA/V = 0.25 m^{-1}

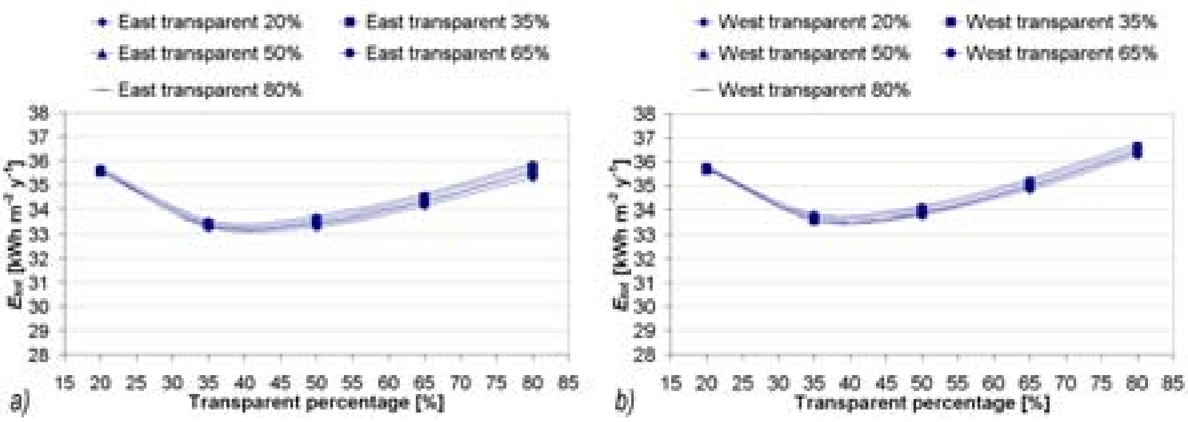


Figure 5. a) Total energy demand E_{tot} for a west-oriented façade module. b) Total energy demand E_{tot} for a east-oriented façade module. SA/V = 0.25 m^{-1}

---

[3] It must be stated that the analysis of a façade alone, without considering the opposite façade is often meaningless, since it is unusual that a building presents one façade alone which borders with the outdoor environment.

In Fig. 4-5, the above mentioned phenomenon can be observed. For each orientation analyzed, five E_{tot} parametric curves were thus obtained, where the parameter is the transparent percentage of the opposite façade. It must be stated that: regardless the transparent percentage of the opposite façade, the difference in the E_{tot} for each transparent percentage is always lower than 3% (south-exposed façade); the parametric curves show the same pattern; the minimum value of E_{tot} is always reached around the same value of transparent percentage. Therefore, it is possible to affirm that the influence of the opposite façade is not particularly relevant, even if it has an influence on the final E_{tot}.

In the case of a south-exposed façade module (Fig. 4a), the optimal configuration has a transparent percentage between 35% and 45%. However, the difference in performance between the "optimal" and the "worst" configurations is about 6%. The performance of the north-exposed façade (Fig. 4b) is also affected by the configuration of the opposite façade. In particular, when the south-exposed façade's transparent percentage is 20%, the performance of the north façade worsens considerably. A less relevant change in the performance of the façade is registered if the south façade has a transparent percentage higher than 35%. The optimal configuration of the north-exposed façade module, regardless the opposite (south) façade module's configuration, is achieved when the transparent percentage is between 35% and 50%.The difference of the performance between the optimal and the worse configuration is more than 11%. The worst configuration is the one with a low percentage of transparent components.

The performance of the west-exposed façade module (Fig. 5a) shows a lower dependence on the configuration of the opposite (east) façade. The dependence increases when the opposite façade has a high transparent percentage (higher than 50%). The difference between the "optimal" configuration and the "worst" one is about 7%. The optimal configuration is achieved when the transparent percentage is in the range of 35-45%. The pattern of the east-exposed façade module (Fig. 5b) is similar to the west-exposed façade. The "worst" configuration is the one with a high transparent percentage (80%), and the best configuration is achieved with a transparent percentage in the range of 35-45%. The difference between the best and the worst configuration is about 8-9%.

Reliability of the optimal configurations

Reliability with respect to the shape of the building

After the analysis was performed on a building with SA/V = 0.25 m^{-1}, two more buildings with different SA/V (cf. Table 1 – SA/V = 0.20 m^{-1} and 0.30 m^{-1}) were equipped with the façade module, and the optimal configuration was searched for these building configurations too. The same procedure described above for the first building was adopted. The aim of this activity is to verify if the optimal configurations found for a building where SA/V is 0.25 m^{-1} were also the optimal configurations for buildings with different shapes. In other words, this phase is aimed at test the stability of the solution with respect to the shape of the building, using the SA/V value as a parameter.

During this phase, the average value of E_{tot} was used for each transparent percentage of the façade module. In fact, as previously described, for each transparent percentage analyzed on the front façade, five different E_{tot} were obtained, depending on the configuration of the back façade. The E_{tot} plotted in Fig. 6-7 is the average of the five different E_{tot} that were obtained from the simulations.This can be done because, as previously described, the influence of the opposite façade is not relevant when the optimal configuration is searched. In fact, it influences the actual energy demand but the optimal configuration is independent from the opposite façade module's configuration.

The analysis on different buildings reveals that the SA/V affects the total energy performance of the building – the lower the ratio, the better. This is a quite predictable property. However, the analysis shows that the optimal façade module's configuration is independent from the SA/V ratio. Furthermore, the optimal configuration is independent from the façade orientation too, as highlighted by the charts below (Fig. 6-7). The three patterns (SA/V = 0.20 m^{-1}, 0.25 m^{-1}, 0.30 m^{-1}) are very similar and the minimum value is always reached in the same interval, regardless the SA/V.

A more detailed analysis reveals that the different SA/V have a relevant influence on the energy demand for heating E_h. On the contrary, the energy demand for cooling E_c and lighting E_l is almost independent from the SA/V. These facts can be noticed in Fig. 8-9.

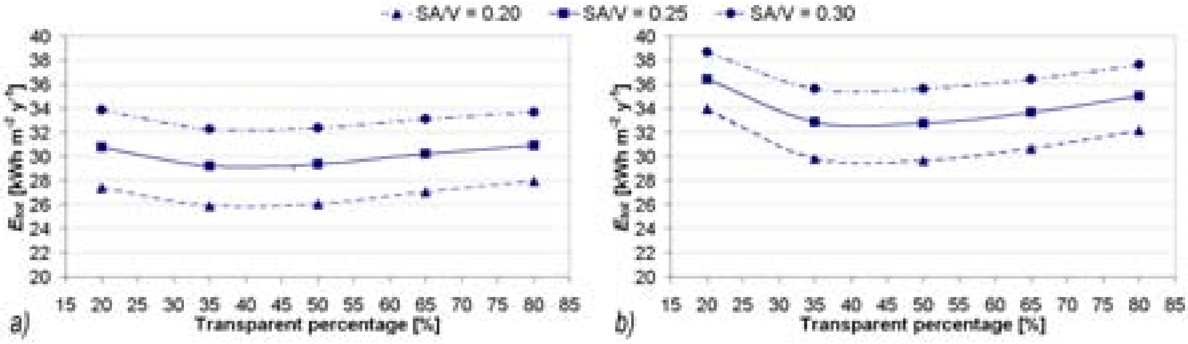


Figure 6. Total energy demand E_{tot} for different SA/V buildings: a) south-oriented façade module b) north-oriented façade module

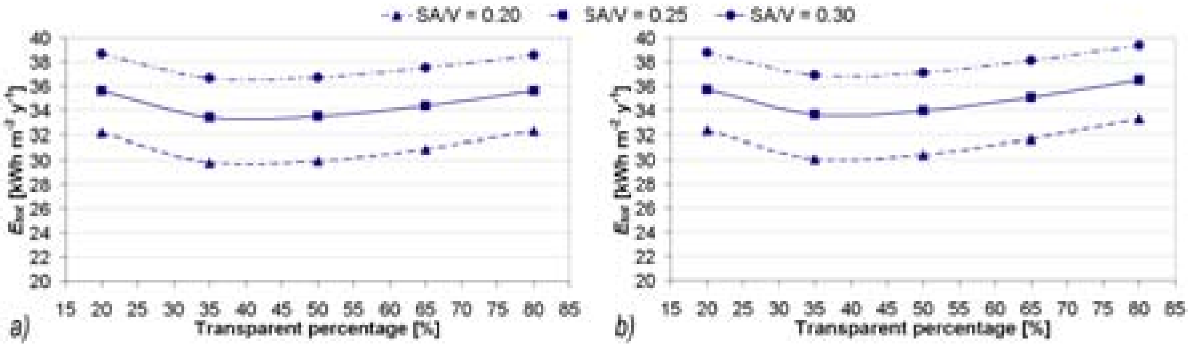


Figure 7. Total energy demand E_{tot} for different SA/V buildings: a) west-oriented façade module b) east-oriented façade module

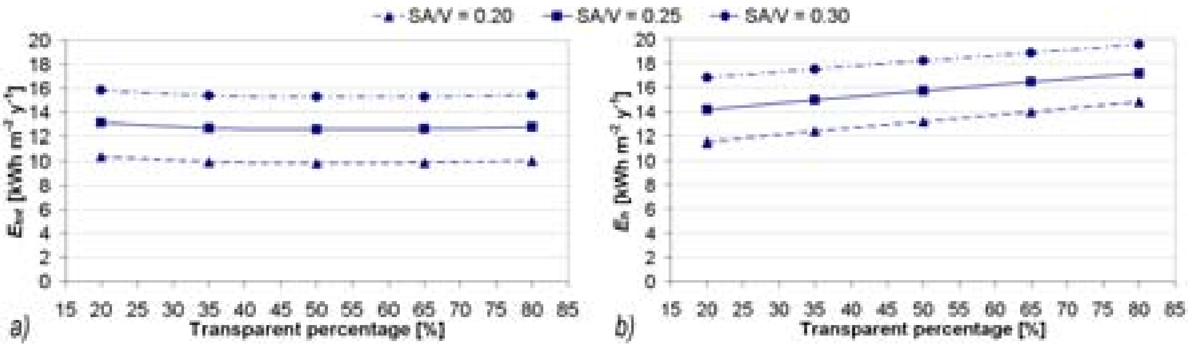


Figure 8. Heating energy demand E_h for different SA/V buildings: a) south-oriented façade module b) north-oriented façade module

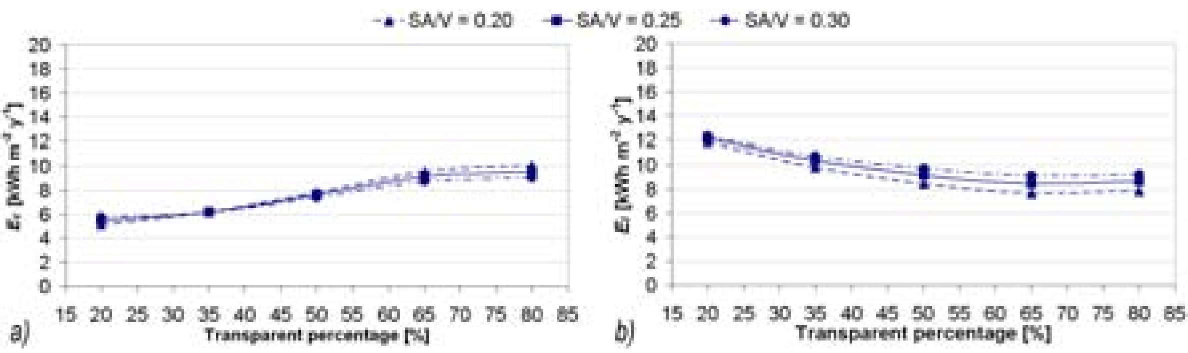


Figure 9. a) Cooling energy demand E_c for different SA/V buildings in a south-oriented façade module b) Lighting energy demand E_l for different SA/V buildings in a south-oriented façade module

In Fig. 8, the primary energy demand as a function of the transparent percentage of the façade module is presented, for a south-oriented and a north-oriented façade module. It is possible to notice that the three patterns (SA/V = 0.20 m^{-1}, 0.25 m^{-1}, 0.30 m^{-1}) are similar but with a difference in magnitude. This difference is caused by the different shape of the building – i.e. the different ratio between the surfaces that borders with the outdoor environment and the heated volume. It is also possible to notice that E_h is not really affected by the transparent percentage, in a south oriented façade (Fig. 8a). This is probably due to the relatively high density of the internal loads, which contribute to reduce the energy demand for heating. Passive use of solar energy (solar heating), which might occur in case of large transparent surfaces, seems to have little or no influence on the energy demand. On the contrary, in the case of a north-oriented façade module (Fig. 8b), a higher transparent percentage in the façade module determines a higher energy demand for heating E_h.

In Fig 9a, the cooling energy demand E_c as a function of the transparent percentage of the façade module is plotted. It is possible to notice that the three plots related to the three different SA/V values are very similar in shape and in values. This means that the SA/V has little or no influence on the cooling energy demand. For the SA/V = 0.25 m^{-1} case, the cooling energy demand may increase by more than 70% from the "optimal" case to the "worst" case. However, the trend does not show a linear behaviour as the transparent percentage increase.

In Fig. 9b the energy for lighting E_l as a function of the transparent percentage of the façade module is plotted. The energy for lighting shows also a low dependence on the SA/V, mainly due to the fact that in the simulated buildings, the higher the SA/V, the higher the ratio between the office rooms (that can exploit daylighting) and other spaces (that cannot exploit daylighting). As expected, the lowest energy consumption for lighting is achieved when a large percentage of the façade is transparent. The energy need for lighting can be increased by more than 40%, if the worst configuration is chosen. Even though in Fig. 8-9 only the data of a south-exposed and north-exposed façade module are reported for the sake of brevity, the analysis of the other two orientations shows the same trend and similar explications can be given.

Reliability with respect to the HVAC system efficiency

The stability of the optimal façade configuration with respect to different efficiencies of the HVAC system was also investigated. The efficiency of the SCOP was increased by 25% by decreased of 25%. 4 possible configurations were evaluated: 1) a reference SCOP heating and an more efficient SCOP cooling; 2) a reference SCOP heating and a less efficient SCOP cooling; 3) a more efficient SCOP heating and a reference SCOP cooling; and 4) a less efficient SCOP heating and a reference SCOP cooling. The four HVAC configurations used to asses the reliability of the solution with respect to different HVAC systems, together with the reference HVAC, are summarized in Table 5. The reference building (SA/V = 0.25 m^{-1}) was used during this phase, and the combination of different efficiencies and different building shapes was not investigated.

In Fig. 10-11, the E_{tot} as a function of the transparent percentage of the façade module, in case of HVAC systems with different efficiencies, is plotted. The four main orientations were investigated. It is possible to notice that an improvement/worsening of the SCOP heating determines very little consequences on the shape of the E_{tot} curves. The curves are of course translated because of the higher/lower efficiency of the HVAC system, which cause a decrease/increase in the E_h and therefore in the E_{tot}. The only orientation that is slightly affected by a better/worse SCOP heating is the north (Fig. 10a). However, since the shape of the curves does not change (or change very little), the minimum value of E_{tot} (i.e. the optimal configuration of the façade module) is always reached in the same interval. Therefore, it is possible to state that the optimal configurations are independent from the efficiency of the heating systems – assuming that the SCOP heating stands in the range of +/-25% of the reference SCOP heating equal to 2.6.

An improvement/worsening of the performance of the cooling system has a wider impact on the shapes of the E_{tot} function instead. It is possible to notice that a more efficient cooling equipment flattens the E_{tot} curve, allowing the optimal configuration to be more transparent. For a south-exposed façade module (cf. Fig. 9a), the optimal configuration changes: from a transparent surface of 35-45% to a transparent percentage in the range of 45-55%. This behaviour can be observed for all the other orientations as well (cf. Fig. 9b, 10a, 10b) and follow a very similar trend. A less efficient cooling system also affects the shape of the E_{tot} curve. However, the impact of this change on the position of the minimum value of the E_{tot} function is less relevant: the optimal configuration is almost always a little less transparent (about 5% less) than the one calculated with the reference HVAC system. The south-exposed façade module (cf. Fig. 10a) is the one most affected by the worsening of the cooling equipment's performance.

Table 5. SCOP of the reference HVAC and of the more/less efficient systems

		Reference HVAC	HVAC 1)	HVAC 2)	HVAC 3)	HVAC 4)
SCOP heating	[-]	2.60	2.60	2.60	3.25	1.95
SCOP cooling	[-]	3.80	4.75	2.85	3.80	3.80

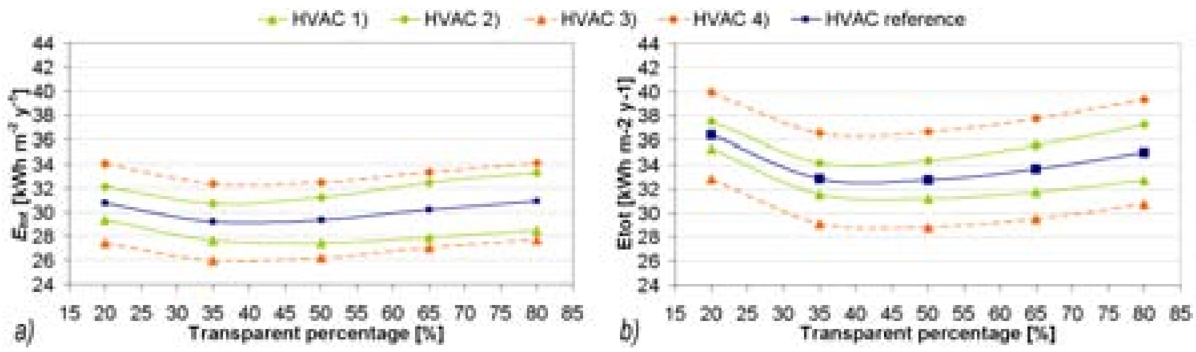


Figure 10. E_{tot} as a function of the transparent percentage in case of HVAC systems with different efficiencies: a) south-oriented façade module b) north-oriented façade module

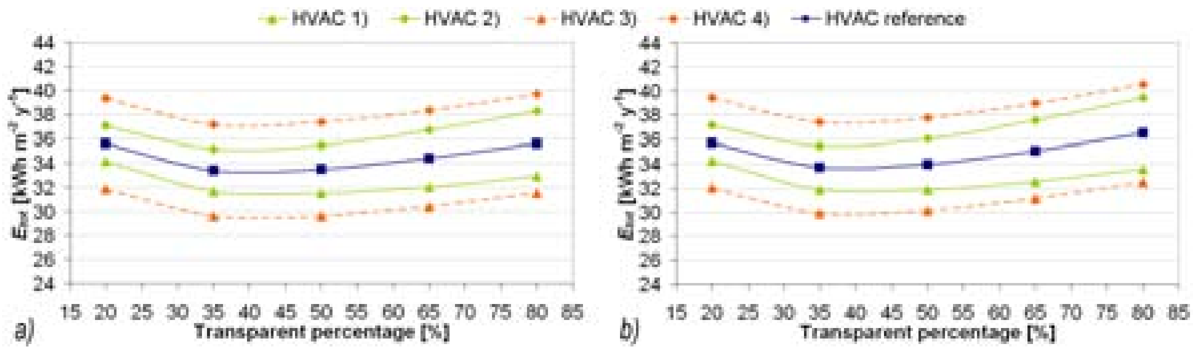


Figure 11. E_{tot} as a function of the transparent percentage in case of HVAC systems with different efficiencies: a) west-oriented façade module b) east-oriented façade module

Discussion

Apparently, the search for the optimal configuration (transparent-to-opaque ratio) of a façade module in an "average" rectangular office building with cell offices reveals that the façade has not a substantial influence on the final energy demands of the building. The optimal configuration can be found, almost regardless the orientation of the façade module, in the range of 35-45% transparent surface and 65-55% opaque surface. The orientation where a "wrong" configuration has the deepest impact on the total energy demand is the north. In this case, an increase of few more than 11% in the E_{tot} with respect to the optimal solution can occur, if a low transparent percentage is chosen (20%). For the other orientations, the increase in the E_{tot} with respect to the optimal solution is between 6% and 9%. It is important to state that there seems not to exist an orientation where the optimal configurations is completely different – i.e. noticeably higher or lower transparent percentage. This is a positive aspect that may allow a simplification to be done, during the first stage of the design of a building, as well as an advantage in terms of prefabrication of the façade modules.

However, it is mandatory to underline that: the technologies that are adopted by the façade are robust and efficient in terms of prevention of heat losses and heat gains; a preliminary optimization of the set-up value for the activation of the solar shading systems was carried out. Thus, the chosen technology and the adopted control strategies were already optimized. To highlight this aspect, it can be mentioned that, if the same façade technology without a solar shading system is simulated, the picture changes drastically: a non optimal configuration of the façade module may determine an increased in the E_{tot} of more than 40%[4] . It is therefore possible to state that the façade configuration has a low impact on the final energy demand, in office buildings, only if the façade is made with up-to-dated technology and managed in a proper way. This may allow building with rather different appearances to be designed, since the transparent-to-opaque ratio may not determine a huge increase in the energy demand of the building. On the other side, it has been highlighted that it is possible to reach an optimal configuration, which may reduce to the minimum extent – as far as allowed by the technology – the total primary energy demand of the building.

Finally, the reliability of the solutions has been tested against different SA/V values and different efficiencies of the HVAC system. The optimal configurations seem to be almost independent from the SA/V value of the building (and therefore from the building shape) and from a different efficiency of the HVAC system – in the range of +/-25% of the efficiency of the reference HVAC system. Only a noticeable increase in the efficiency of the cooling equipment may determine a slightly change in the optimal configurations – allowing more transparent façade modules to be realized and a decrease of the total energy demand achieved.

Conclusion

To assess the optimal configuration (transparent-to-opaque ratio) of a façade module for office building, simulations were performed on an “average” office building, which building envelope was realized with a single skin façade module, made with market-available technologies. Integrated thermal and daylight simulations were realized to take into account the high degree of interdependence between the different energy demands (heating, cooling, lighting) and the final total outcome. The performance of the façade module was therefore assessed in terms of total energy demand and the configuration that minimizes this function was searched.

Different orientations, building shapes (SA/V parameter) and HVAC system efficiencies were taken into account during the analysis. The results show that the configuration of an advanced façade module (with state-of-the-art technologies) has a low influence on the total energy need of the building. The north-exposed façade is the one that may suffer most from a “wrong” configuration, while the south-exposed façade is the one where the influence of the façade configuration is the lowest. The optimal configuration is quite often achieved when the transparent surface is 35-45% of the total module area, and it is little dependence on the building shape and the HVAC’s efficiency.

References

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[2] Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 2007;11(5):1633-1644

[3] IEA-SHC TASK 27: Performance, Durability and Sustainability of Advanced Windows and Solar Components for Building Envelopes.

[4] EnergyPlus Engineering Reference, October 2011

4 This value is obtained simulating the same office configuration (SA/V = 0.25 m^{-1}) with a façade module that does not incorporate a solar shading system, but with the same features (e.g. U-values, SHGH, visible transmittance) of the façade module used in the paper.

Energy Performance Contracting for the German Federal Army Base Oranienstein in Diez

DI Vollrad Kuhn, Business Development Manager Central Europe

Johnson Controls, Building Efficiency, Energy Solutions Central Europe

Abstract

Following a tender initiated in 2007 by the German Federal Army to retrofit several army bases via Energy Performance Contracting (EPC), Johnson Controls was selected to reduce CO_2 emissions and energy consumption in the Oranienstein base of Diez. The biggest challenge of the project was the historic value of the site, on which the army base is situated. The location includes a castle built in the 17th century, restored by the German Government in 1962. Since 2001, the castle hosts not only the medical command center of the German Federal Army, but also the Nassau-Orange Museum. The pool comprises 25 single buildings (including kitchen building, historical castle with museum, storehouses, workshops and buildings for administration and accommodation of military and civil staff and guests).

The project was developed and managed as a two-stage-model by the State owned real estate management institution LBB – based on the common model and guidelines for EPC in Federal sites elaborated by the national German Energy Agency "Deutsche Energieagentur GmbH" (dena).

This project represents a financial and technological innovation for historic sites in Europe. With the help of a 10 years Energy Performance Contract, the German Federal Army base in Diez gains yearly energy cost savings of 231.290 Euros. The simple payback indicates the investment will provide return in 6 years. The investment costs were 1,4 million Euros.

Through this EPC, the German Federal Army (and indirectly the tourists visiting this site) will take advantage of the following sustainable changes:

- Approx. 49% savings in energy costs
- 55% of reduction in CO_2 emissions
- Project financing arranged by Johnson Controls (turn-key project – a Building Cost Subsidy of 526 000 Euros is included)
- No risk for the owner through guaranteed savings by Johnson Controls
- 10 years of full service and savings guarantee
- Same historical meaning for a more sustainable building

Energy Performance Contracting for the German Federal Army Base Oranienstein in Diez

The Building Pool and the Project History

The German Federal Army had started the preparation of Energy Performance Contracting (EPC) for a large pool of buildings of several sites in the State of Rhineland-Palatinate *(Rheinland-Pfalz)* in the western part of Germany in 2007. It was divided into three separate lots, the sites and buildings of the army base Oranienstein in Diez was defined as lot 2. It comprised at the beginning of the project a pool of 35 buildings with a total area of 45.700 m^2.

The regional Service Center of the Federal Army – acting as purchaser and contracting entity on behalf of the army as the site and building owner - initiated the energy retrofit of the buildings of the military base complex as an EPC project in order:

- to save energy, costs and reduce CO_2 emissions without own risks,
- to reduce the own capital costs for the investment to a fixed construction subsidy,
- to get all services including maintenance of the new installed Energy Conservation Measures from the Contractor,
- but also to improve the comfort conditions for the soldiers and officers, the staff and also visitors of the museum and other guests.

Because the State owned real estate management institution LBB was already responsible for energy management and other services in Federal army sites, the regional LBB office was also involved in the project preparation and procurement.

The biggest challenge of the project was the historic value of the site, on which the army base is situated. The location includes a castle built in the 17th century, restored by the German Government in 1962. Since 2001, the castle hosts not only the medical command center of the German Federal Army, but also the Nassau-Orange Museum.

Historical castle Oranienstein of the Federal army base Diez *(source: JCI)*

The project was developed and managed as a two-stage-model by the LBB – based on the common model and guidelines for EPC in Federal sites elaborated by the national German Energy Agency dena.
LBB was commissioned to prepare the project including provide the technical assistance for the procurement.
The planned timeline of the 10-year-project was the following: request for proposal mid of December 2007, submission of proposal mid of March 2008, end of May awarding of EPC contract, fine analysis report 1st week of July 2008, construction phase until end of December 2008. This timeline was a bit unrealistic considering all the experiences which had been gained during the project realization by all involved project partners.

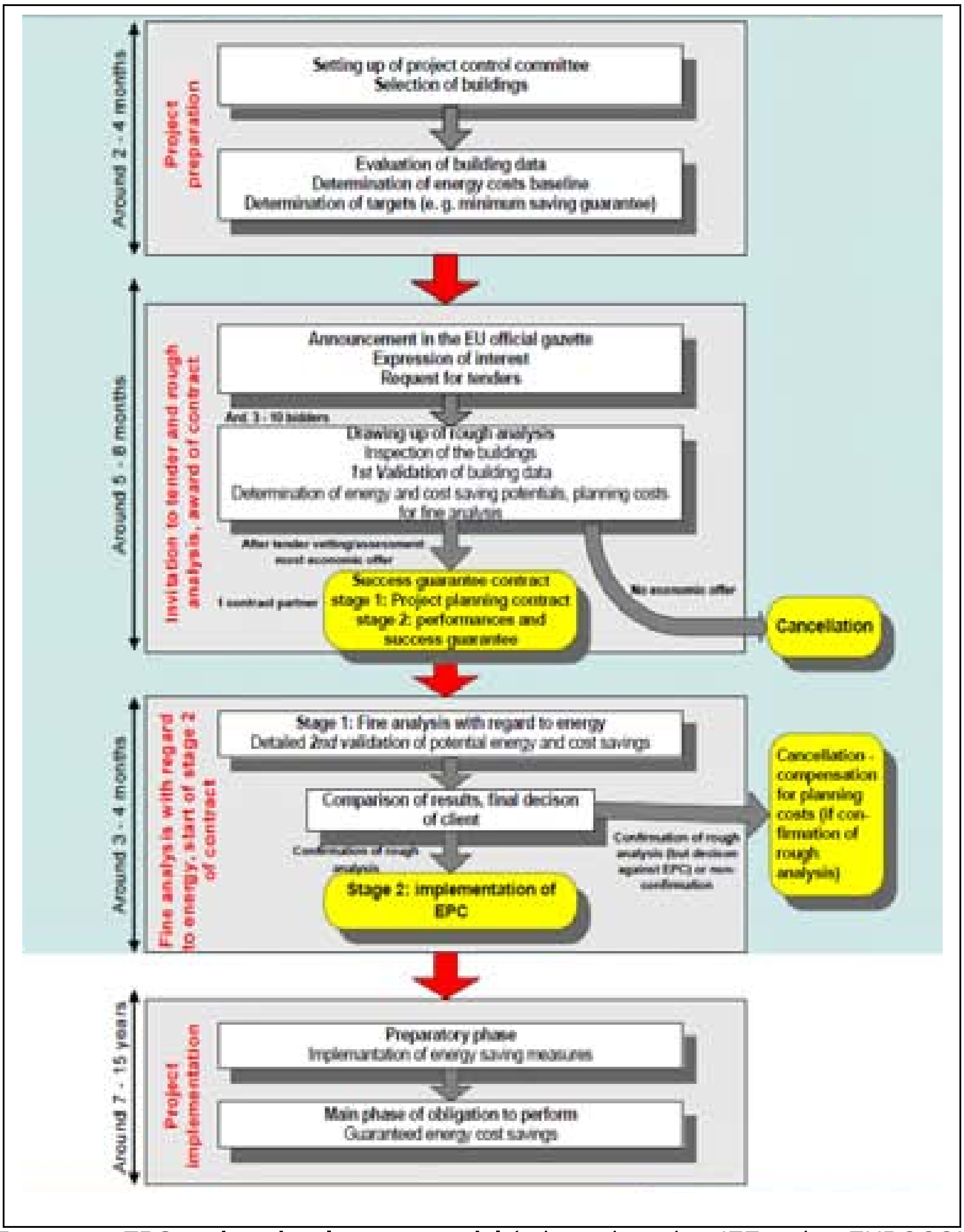
Project Model and Role of Energy Agencies dena and BEA

The EPC project was developed based on the two-stage-model approach which is common especially for complex EPC projects in Germany and other countries. First versions of such models were elaborated at the beginning of 1990 years in Germany, e.g. by the regional tax office Stuttgart for use in EPC projects in public buildings, followed by an one-stage-model developed by the State Ministries for Environment in Hesse and Berlin with the support of the Berlin Energy Agency (BEA).

BEA was established as public-private owned company in 1992, has elaborated several EPC models and guidelines and is one of the main supporters and promoters of EPC in the national and international market.

The dena was set up as public-private owned national German Energy Agency end of 2000 and had established a “Competence centre for Contracting” within the building division during the last two years. It is responsible for preparation/development of Contracting models and concrete projects for sites and buildings owned and/or managed by Federal ministries and similar institutions, for technical assistance, Know-how transfer and image and awareness rising activities on Contracting issues. Dena had created a two-stage-model and a guideline for EPC in Federal buildings as one of its firsts activities. The “Competence Center for Contracting” is also organizing and conducting expert workshops on contracting issues and has established a working committee for information exchange and EPC model development with other experienced German energy agencies (e.g. BEA), the German trade association of ESCO's (VfW – Association for heat supply - with the working committee for EPC) and other experts and institutions.

The figure below gives an overview on the model, the four main phases including the estimated time period for each of the phases and the options for the building owner as one of the project parties. It shows the general model approach which was used also for the Federal Army EPC project in Diez.



Two-stage EPC project development model *(scheme based on IEE project EUROCONTRACT)*

Project Milestones and core content of tender

The first project activities were started by LBB and Federal Army (supported by the regional Service Center of the army) in early 2007 to collect the first data, check the saving potential and discuss the potential model for procurement and project realization. After getting a preliminary understanding about the saving potential, advantages and feasibility of an EPC in comparison to a traditional procurement of single retrofit measures financed by an internal capital budget the final go-ahead decision of the owner to start with tender preparation for the EPC followed. The announcement was published in summer 2007 in the official EU gazette together with a request for qualification. Johnson Controls was qualified based on the submitted qualification documents and was invited to submit an offer.

The project timeline given within the tender documents was the following:

- handing over of tender documents, request for proposal: mid December, 2007
- time for rough analysis, site visits etc. by bidders: 6 weeks until mid of February 2008
- deadline for submission of offers: mid of March 2008
- negotiation rounds with best bidders April – May 2008
- awarding of the EPC and signing of the EPC contract: end of May 2008
- deadline for submission of fine analysis by the ESCO: 1st week of July 2008
- final decision by the owner to implement the EPC: 1st week of August 2008
- construction and implementation phase: until end of 2008
- main phase with obligation for ESCO to perform: 10 years

Core content of the tender documents was the EPC template contract with seven annexes, similar to the dena EPC model template from the dena guideline for “the preparation and implementation of EPC in Federal sites”[1]. The tender specification provided detailed information concerning the tender, the timeline, the EPC model template, the procedure for rough and the fine analysis, the reference cost baseline for 2006 (final adapted beginning of 2008) with

- 475.602 EUR (net) for electricity, fuel (gas, oil), water/sewage and
- the evaluation criteria for assessment of the offers (see below).

The assessment of the offers would be conducted using a net-present-value (NPV) method with the following components of the NPV:

- guaranteed energy cost savings (related to the baseline)
- share of the savings for the building owner
- amount of hardware investment
- amount of construction subsidy (to be provided by the owner if necessary)
- term of estimated construction period

A combined NPV-benefit-analysis should be used for the final evaluation with following weighting factors:

- NPV-value 75%
- Bonus-share of the building owner on the savings beyond the guaranteed value 5%
- Technical-organizational concept of the planned measures 5%
- Financing concept including forfeiting 5%
- Quality and compatibility of the technical plants and components to be installed 5%
- Use of environment friendly technologies, CO_2-mitigation 5%

Additional information was given concerning the technical offer conditions, among others to the following four compulsory measures:

- planning, installation of a building management system (BMS) ready for operation
- installation of consumption meters including connecting of consumption data of the single buildings onto the BMS
- realization of an economically feasible concept for the supply of selected buildings with hot portable water
- realization of an economically feasible concept for central plant for water softening

[1] Dena guideline for “the preparation and implementation of EPC in Federal sites”

Special importance was given to the potential use of environment friendly technologies like renewable energy technologies.

Successful Project Proposal of JCI

Johnson Controls won the public tender to transform the selected buildings of the Federal Army base Oranienstein in Diez into high efficiency buildings with the best economic offer and assessment results on the end of tender vetting. The EPC contract was signed by both partners 1st of August 2008, followed by a separate planning contract to conduct the fine analysis. As result of the rough analysis Johnson Controls had given a saving guarantee of 215.835 EUR (about 45% cut in annual energy costs), the reduction of annual CO_2 emissions was estimated by 1.060 t (approx. 50%).

Further investigations in the frame of following fine analysis – conducted until end of October 2008 by the experienced engineers of Johnson Controls - including the adaptation of some energy conservation measures and creation of additional smart solutions - revealed that the energy and CO_2 saving potential was higher: the guaranteed annual energy savings were increased to 234.021 EUR (49,2%) and the CO_2 reductions to 1.264 t (55%) in comparison to the offer based on the rough analysis results.
The total investment (hardware, planning costs) was calculated to be about 1,37 Mio. EUR including a necessary construction subsidy (to cover the investment costs by the saving potential) of about 0,5 Mio. EUR. The construction subsidy was defined as optional in the tender documents – but should be provided from the building owners capital budget.
The new date for starting of the phase with main obligation to perform was fixed for beginning of November 2010.

Project Realization and actual Status

In order to make the Oranienstein base more energy efficient, strict regulations needed to be taken into account. That was also the reason to reduce the number of the buildings which should be considered for the retrofit to about 25 (including kitchen building, historical castle with museum, storehouses, workshops and buildings for administration and accommodation of military and civil staff and guests).

During the preparatory phase for implementation of the energy conservation measures several options came out and had to be discussed with the building owner and LBB. Finally the partner agreed to a few amendments of the existing EPC contract due to some necessary changes of the measures, e.g. related to the installation of two gas-fired CHP units, the necessary gas pipe connection and the installation of a woodchip-fired boiler including the necessary technical and logistic infrastructure.

In this special context, the retrofit and improvement measures included:

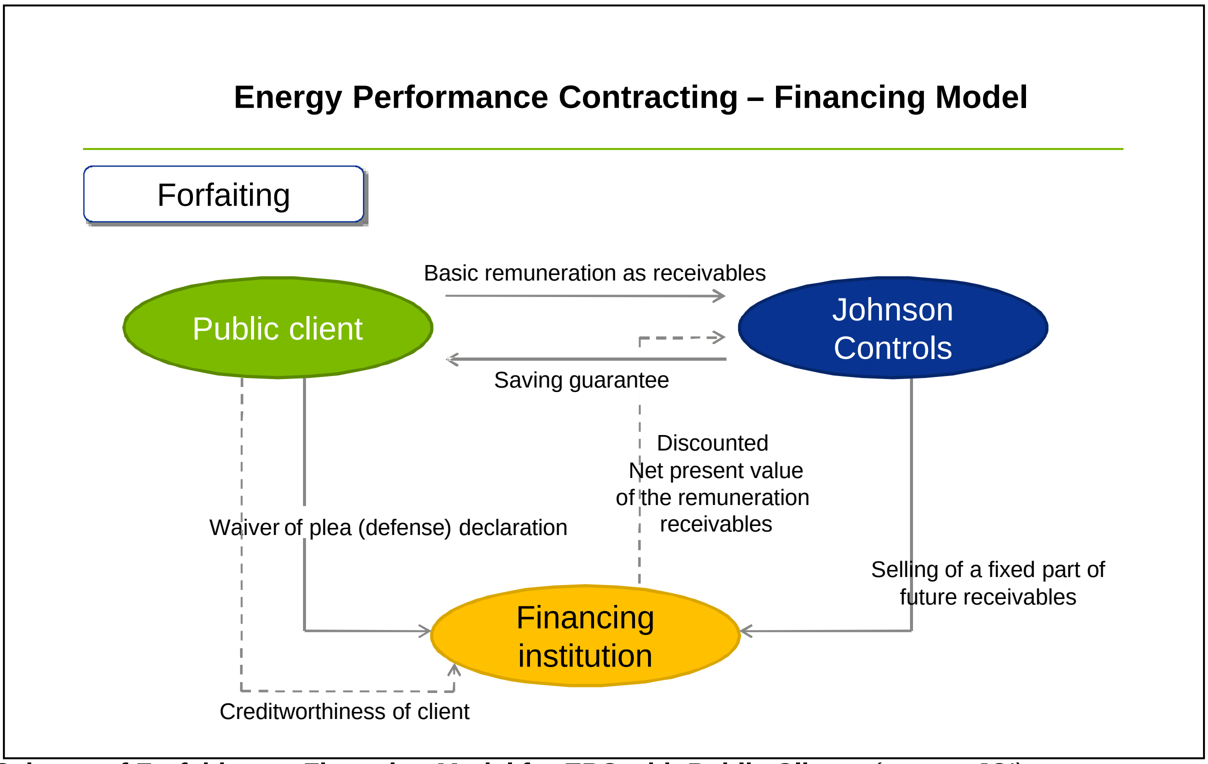
- Replacement of a 850kW dual fuel boiler with a woodchip boiler including woodchip storage, mechanical transport systems, chimney, buffer storage etc.
- Installation of two mini gas-fired combined heat and power plants (CHP) with 15kW el. Power, 30 kW thermal power and the buffer storage, connecting with the heat distribution grid
- Construction of a gas pipeline to connect the CHP with the gas supply system
- Change of warm water supply in several buildings
- Installation of a central water-softening plant
- Replacement/renewing of the lighting system
- Installation of meters and the modernization of the Building Management System (BMS) including migration of the existing systems
- Change of the pump control to pressure control
- Installation of M-bus meters
- Optimization of Direct Digital Controls (DDC)

Installation of the new woodchip-fired boiler into the boiler house *(source: JCI)*

Final installation of a gas-fired CHP-unit *(source: JCI)*

The total investment costs were increased to about 1,42 Mio. EUR, the guaranteed savings had to be reduced a little bit to 231.290 EUR (48,6% in comparison to the baseline costs) – but it was still more than 3,5% higher than the saving guarantee given in the first offer after the rough analysis.

The project financing of the project was structured including a forfaiting solution (core element is the assignment of receivables from the ESCO to a financing institution to get the upfront funding of the invest costs) which was allowed under the EPC contract. One main advantage is that the lower interest rate is reducing the total project costs and also the remuneration of the ESCO to be paid by the public building owner as Contracting fee. Forfaiting is gaining popularity as financing instrument for EPC projects especially with regard to transactions with the public authorities. The following schemes shows the main principle:



Scheme of Forfaiting as Financing Model for EPC with Public Clients *(source: JCI)*

Due to the necessary adaptation of the project, the additional contracting of Johnson Controls to supply the woodchips and change of responsibilities by the owner some delays occurred. Nevertheless the phase with main obligation to perform began in November 2010 and will last until end of October 2020 (120 months).

Most of the plants and solutions - suggested, planned and implemented by Johnson Controls in the frame of the energy conservation measures - are working without problems and are reducing the energy and water consumption significantly. A problem was the operation of the woodchip-fired boiler due to different quality of the woodchips, the lack of experiences with such solutions and missing support by technical staff of the owner. But it seemed to be only starting problems of such a complex project. Johnson Controls is convinced they will achieve the guaranteed results in the actual running phase with main obligation to perform.

Benefits for the Client, Lessons learned and Conclusions

This project represents a financial and technological innovation for historic sites in Europe. With the help of a 10 years Energy Performance Contract, the German Federal Army base in Diez gains yearly energy cost savings of 231.290 Euros. The simple payback indicates the investment will provide return in 6 years. The investment costs reach 1,4 million Euros.
Through this EPC, the German Federal Army and indirect the tourists visiting this site will take advantage of the following sustainable changes:

- Approx. 49% savings in energy costs
- 55% of reduction in CO_2 emissions

- Project financing arranged by Johnson Controls (turn-key project – a Building Cost Subsidy of 526 000 Euros is included)
- No risk for the owner through guaranteed savings by Johnson Controls
- 10 years of full service and savings guarantee
- Same historical meaning for a more sustainable building

Such problems like the difficult operation of the woodchip-fired boiler due to different quality of the woodchips, the lack of experiences with such solutions and missing support by technical staff of the owner could be occur in similar projects and should be solved by a detailed planning of operation, the clear description of all interfaces and responsibilities of ESCO and owner (with regard to operation, maintenance etc.) and especially the organizing of woodchip procurement based on a contract with clear quality criteria.

The Oranienstein Base in Diez has the potential to exemplify how historic valuable sites can become a sustainable resource for future generations. Johnson Controls made that possible by matching history and today's technology. This best practice project is a good example for using of EPC as a turn-key approach to retrofit buildings and save energy costs and reduce CO_2 emissions for public owners with large building portfolios and retrofit needs, but missing resources to realize it in own direction. The ESCO is taking over such main risks like the economic and technical risks and is organizing in most of the cases in Europe the funding of the investment in energy efficiency solutions.

The used EPC model is common in Germany especially for projects with larger building pools and complex buildings. Such standards like the dena EPC guideline or the Hesse EPC guideline[2] including the EPC model template and the increasing confidence in the procurement of energy services like EPC via functional tenders and negotiated procedures by public building owners are essential for better utilization of market potential of energy services. German is Europe's largest and most mature ESCO market[3]. Experienced energy agencies and consultants are providing technical assistance and support for the building owners in developing, preparing and tendering of Contracting projects, and a growing number of ESCO's – most are organized in the trade associations VfW (Association for Heat Supply), DENEFF (German Energy Efficiency Initiative of Companies) and the ESCO Forum within the ZVEI (Central Association of the Electrical Industry) – are participating on the competitions of best economic ideas and solutions in the frame of tenders.

[2] Hesse Contracting guideline for public sites

[3] ESCO Market in Europe, status report 2010

References

References

[1] Petra Bühner, Jens Gröger, Deutsche Energieagentur GmbH (dena): *Leitfaden Energiespar-Contracting (Guideline Energy Performance Contracting)*, published in 2003, the last revised version in 2008, can be ordered from www.dena.de , info@dena.de

[2] Friedrich Seefeldt, Vollrad Kuhn, RA Wolfgang Trautner, RA Jan-Hendrik Wetters: *Leitfaden für Energiespar-Contracting in öffentlichen Liegenschaften (Guideline Energy Performance Contracting in public sites)*, published in 2003, the last revised version – elaborated again by Berlin Energy Agency - shall be published in Spring 2012, can be ordered from Hesse Ministry for Environment, Energy, Agriculture and Consumer Protection www.hmuelv.hessen.de , oea@hmulv.hessen.de

[3] Angelica Marino, Paolo Bertoldi, Silvia Rezessy; European Commission, JRC Institute for Energy: *Energy Service Companies Market in Europe – Status report 2010),* published 2010

New business models for a low carbon future: the importance of third party finance in the UK

Dr Mark Hinnells

Environmental Change Institute, University of Oxford, and Solutions Director, Susenco Management Limited

Abstract

The paper argues that third party finance (known as off-balance sheet finance, or off debt in the public sector) is key to delivering the demanding carbon reduction targets of an 80% cut now being pursued in the UK.

The paper explores the evolving UK policy framework. Low carbon solutions include energy efficiency, combined heat and power and renewables all of which can be embedded within a site.

The paper explores barriers to uptake of low carbon solutions including lack of capital, lack of management time, lack of knowledge and a risk averse attitude to investment. Two thirds of UK property is leased, and the landlord tenant relationship adds particular difficulties.

Off balance sheet finance allows someone else with the time, money, knowledge and risk-appetite, to deliver a solution that the host would not have been able to deliver alone. The paper explores how third party finance solutions work currently in the UK; identifies the size of the opportunity in the UK; and how UK policy could support development of this market.

If the UK carbon target is to be met, and in a timely way, it is key for Government to realize it can be a market maker, not only by way of creating exemplars in the Government estate, but in how it sets market rules. If this happens, the market place for energy supply and energy efficiency will become unrecognisеable. New entrants are providing third party solutions, but from existing businesses in adjacent business fields, rather than start-ups with significant partnering and acquisition activity.

Introduction

The UK is seeing a period of rapid policy change to achieve a low carbon economy including setting in an act the target of an 80% reduction in carbon emissions, and changes to the electricity market to deliver a step change in the level and type of energy investments. Commercial property owners struggle with low carbon solutions. This paper argues that third party finance (or off balance sheet finance as it more commonly referred to in the UK and off-debt finance in the public sector) is critical to delivering the target in anything like the timescales envisaged, and that it will lead to the emergence of a new set of market players. Off balance sheet finance allows someone else with the time, money, knowledge and risk-appetite, to deliver a solution that the host would not have been able to deliver alone.

UK Energy and Climate Change Policy

The UK is seeing a period of rapid policy change to drive a low carbon economy. The centerpiece of this is the Climate Change Act 2008 [1] which sets out the target of at least an 80% cut in carbon emissions by 2050, with a 5 yearly budgeting process towards the target. Budgets have been set as far as 2027 (in black below, with indicative budgets to achieve the planned 80% reduction in grey).

UK Carbon Budgets under the UK Climate Change Act

		Carbon budgets (MtCO2e)	% reduction below 1990 levels
Budget 1	(2008-12)	3018	23%
Budget 2	(2013–17)	2782	29%
Budget 3	(2018–22)	2544	35%
Budget 4	(2023-27)	1950	50%
Budget 5	(2028–32)	1716	56%
Budget 6	(2033-37)	1482	62%
Budget 7	(2038-42)	1247	68%
Budget 8	(2043-47)	1013	74%
Budget 9	(2048-52)	779	80%

This Act has been followed up with a series of reforms to the energy market which aim at decarbonising the electricity grid by 2030 as a major contribution to decarbonising the economy. This requires a step change in the level and type of investment, estimated at £110billion investment in UK energy supply. A White Paper outlined Electricity Market reforms [2] including

- a Carbon Price Floor to reduce investor uncertainty, putting a price on carbon and intending to provide a stronger incentive to invest in low-carbon generation now;
- the introduction of new long-term contracts (Feed-in Tariff with Contracts for Difference) intended to provide stable financial incentives to invest in all forms of low-carbon electricity generation which the Government sees as including renewables, nuclear and carbon capture and storage;
- an Emissions Performance Standard (EPS) set at 450g CO_2/kWh to reinforce the requirement that no new coal-fired power stations are built without CCS (but allowing gas generation to be built without requiring CHP); and
- a Capacity Mechanism, intended to reward demand response as well as generation, which is needed to ensure future security of electricity supply.

These reforms builds on existing fiscal measures which include:

- renewable Obligation Certificates for large renewables and Feed In Tariffs for smaller schemes (less than 5MW) [3],
- the Renewable Heat Incentive for low carbon heat supply [4],
- the Green Deal to fund energy efficiency refurbishments for homes and businesses, recovering the cost from savings on the energy bill [5],
- and the CRC Energy Efficiency Scheme (which is an additional tax on carbon emissions from businesses and creates a league table for carbon emissions, though this is going through a series of simplifications) [6].

Fiscal measures are supported by regulatory measures, including ongoing reform to planning (with a presumption in favour of 'sustainable development' in a new National Planning Policy Framework [7], continuing improvements to building regulations [8], and strong support for product policy at EU level, both in terms of labels and standards, in the shape of the Market Transformation Programme [9].

In addition to national policy there are local targets and measures. For example, the London mayor has set his own targets to put London in a leadership role within the UK, achieving the targets for the UK by up to 10 years with a 20% cut in CO2 by 2015, 38% by 2020 and 60% by 2025 [10]. To underpin these targets there are a series of local programmes:

- RE:NEW – retrofitting London's homes with energy efficiency measures, and helping Londoners save money off their energy bills [11].
- RE:FIT – retrofitting London's public sector buildings [12].

- RE:CONNECT – ten low carbon zones supporting community led initiatives and behavioural change in London aiming to reduce CO_2 emissions by 20% by 2012 across the community [13].
- Decentralised energy programme – aiming to supply 25 per cent of London's energy from secure, low carbon local sources [14].

With this background, the UK and London in particular is well equipped to utilise EU programmes like ELENA (which provides technical support (engineering tax and legal consultancy) to a local authority led initiative) [15], JESSICA (Intermediated loans, ie working 50:50% with local banks, to provide loans to SMEs including ESCOs) [16], and EEEF (lending to market rates but a technical assistance programme) [17].

The challenge is whether the policy framework outlined above, radical as it is, is sufficient to overcome the barriers to change and deliver the targets, and how this might influence the evolving market for third party or off-balance sheet solutions.

Barriers to reduced carbon emissions

Commercial property owners and occupiers act in the context of this market (knowingly or otherwise, in anticipation, or in reaction). Barriers to change been studied for many years, since Golove, and Eto in 1996 [18] identified a range of barriers to energy efficiency including transaction costs, asymmetric information between customers and energy providers, and the fact there is no single market for energy services, instead, the "market" consists of hundreds of end uses, thousands of intermediaries, and millions of consumers. The author has both an academic role and a practitioner role, and as a practitioner observes first hand that the barriers to low carbon include lack of capital, lack of management time, other higher priorities for both time and money, lack of knowledge and perhaps because of this, a risk averse attitude to investment.

Barriers are compounded when the occupier of a property is not the property owner but a tenant, whilst the owner is an investor seeking the best commercial return on the asset. The author as academic has explored the impact of the leasehold relationship on delivery of energy efficiency and renewable investments [19], [20]. In the UK around two thirds of commercial property is leased (which may be much higher than elsewhere), and this proportion is rising through a long term trend of 'sale and leaseback' (selling their property portfolio to an investor, and renting them back). It is a common view in many sectors (eg retail, office based businesses and warehousing) that outsourcing real estate needs will make a business more efficient and flexible in space use. This has also allowed capital receipts to be reinvested in the core business.

The implications for energy efficiency and renewables are that investments in lighting and equipment, heating systems, power generation, control and monitoring systems, and fabric measures could cut across the landlord and tenants responsibilities. In addition, it is not uncommon to find a responsibility for investment might lie with the landlord, but it is the tenant that makes the saving. Or if responsibility for investing does lie with the tenant, they would not be able to recover the full benefits before the lease expires, or worse, they could be required to reinstate the changes at the end of the tenancy. Whilst leases have been for up to 25 years, generally they are getting shorter. Whatever the remaining length of the lease it is likely that payback has to be within the remaining life of a given lease, or there has to be clear residual value which can be accessed by the investor at the end of the lease. For investment to happen, it has to suit both landlord and tenant, and a way has to be found of making sure that benefit is gained by the party carrying the cost.

Sometimes the facility is managed by a third party. However, Facilities Management (FM) can be focused on provision of basic services (cleaning and concierge) whilst minimizing short term costs (certainly in the UK context), without any long term perspective. This has been illustrated by one service provider as "year 1, understand contract, year 2 deliver contract, year three re-tender contract". An energy services provider may have to work alongside an FM provider. There is however, evidence of some FM companies (like MITIE) expanding their service offering to include energy services.

A number of ways of greening the commercial leasehold relationship are explored in [19], [20], as well as more recently in [21]. As incentives increase to implement energy efficiency and renewable energy, owners and occupiers of commercial and residential property may not be in a position to deliver solutions themselves, but instead, need to find others to deliver solutions on their behalf using third party finance. This allows someone else with the time, money, knowledge and risk-appetite, to deliver a solution that the host would not have been able to deliver alone.

Indeed Golove and Eto [18] believed multiple, complementary approaches tailored to particular circumstances would be more likely to succeed in overcoming market failures or reducing high transaction costs. Further they believed “an important role of government may be to create new market institutions that will be self-sustaining following an initial stimulus from the government”, that is, third party actors including providers of energy services.

Defining solutions

Potential solutions now explored include what is meant by third party, or ‘off balance sheet’ and, just as important for the public sector ‘off debt’. Current models of energy services are also explored, because there are a wide range of potential structures in the UK in particular, and some of these are different to what has been seen elsewhere.

There is nothing new in this model, it has been seen across both western and eastern Europe as well as the US. It is a model which hitherto has struggled to establish itself in the UK, and though arguably its time has arrived, this has been said before. There will however be differences in how this model develops in the UK from elsewhere.

What is off balance sheet?

International Financial Reporting Standards (IFRS) are principles-based standards [22].The formal accounting distinction between on and off-balance sheet items can be quite detailed and will depend to some degree on management judgments, but in general terms, an item should appear on the company's balance sheet if it is an asset or liability that the company owns or is legally responsible for.

Capital expenditures are kept off of a company's balance sheet through various classification methods. Companies will often use off-balance-sheet financing to keep their debt to equity (D/E) and leverage ratios low, especially if the inclusion of a large expenditure would break debt covenants. This is in contrast to loans, debt and equity, which do appear on the balance sheet. Examples of off-balance-sheet financing include joint ventures, research and development partnerships, and operating leases (rather than purchases of capital equipment).

Operating leases are one of the most common forms of off-balance-sheet financing. In these cases, the asset itself is kept on the lessor's balance sheet, and the lessee reports only the required rental expense for use of the asset. Generally Accepted Accounting Principles (GAAP) [23] have set numerous rules for companies to follow in determining whether a lease should be capitalized (included on the balance sheet) or expensed.

However, whatever accounting practice dictates, in terms of addressing barriers, there is another altogether more subtle and important point. If the finance is off balance sheet, management time and mental space is off balance sheet, the due diligence is off balance sheet, and off risk register.

Off debt

'Off debt' is as important to government as 'off balance sheet' is to the private sector. Off debt is defined in International Financial Reporting Standards (IFRS), and the simpler, European Standard Accounting ESA95 [24]. An asset is ‘off debt’ if it is

- A Public Private Partnership, i.e. services purchased on the basis of a dedicated asset, or if a significant new asset, and if there are deductions for failures to provide, and construction, availability and demand risk.
- A Concession arrangement, i.e. the corporation operates asset and charges users. A project is off debt if the majority of private revenues are from a charge to services users. However, it is contingent on the details of the arrangement.
- Energy Service provision is off debt if assets are not clearly defined, if other entities may use assets eg by removal and redeployment, or the provider funds capital and operating costs from

agreed share of cost reductions with no 'hell or high water' payments. Thus it is necessary to make any guarantee contingent on things that may or may not happen.

There would be value in specific guidance for the UK (Her Majesty's Treasury usually issues these in the form of an Application Note or Guidance Note) to outline and clarify the issues and give clear policy support to off debt solutions in the public estate.

Defining energy services

Low carbon solutions include energy efficiency and also on-site power generation options such as combined heat and power (using a range of fuels) and onsite renewables (like wind and energy from waste). Different commercial structures and deal structures have been seen for each.

Energy service contracting is a form of outsourcing. To paraphrase Sorrell [25] it will only make sense where the expected reduction in the production cost of supplying energy services can more than offset the transaction cost of negotiating and managing the relationship with the energy service provider. Transaction costs are determined by the complexity of the energy service, the 'specificity' of the investments made by the contractor, the competitiveness of the energy services market and the relevant legal, financial and regulatory rules. Outsourcing energy services is better suited to larger users unless transaction costs can be minimised through simple standard contracts. Production costs will be determined by a combination of the physical characteristics of the energy system and the technical efficiency of the relevant organisational arrangements, including economies of scale and specialisation.

There are many definitions of energy services appropriate to energy efficiency offerings, rather than to renewable or low carbon energy supply and a range of contracting models, with more detailed definitions in Bertoldi et al [26] which provides a review of the ESCO markets in the EU and Sachwel et al provide the same for the US [27]. Commonly an energy service company is taken to be a commercial business providing a range of energy solutions including design and implementation of energy saving projects, energy infrastructure outsourcing, power generation and supply of back up and top up power fuel or heat, and risk management. Commonly an ESCO performs an in-depth analysis of the site, designs energy efficient solutions, installs the required elements, and maintains the system to ensure energy savings. The savings in energy costs is often used to pay back the capital investment of the project over a five- to twenty-year period, or to cross-subsidise upgrades that may otherwise be unfeasible. If the project does not provide returns on the investment, the ESCO is often responsible to pay the difference.

Bertoldi, Hinnells and Rezezy [28] identified three distinct types of market for energy services in the UK. First, the commercial and industrial sector, using a 'facilities management' or 'performance contract' model, where the ESCO offering is most developed, and where there remains great potential. Second a community model, where decisions are taken by or on behalf of a group of customers in the same location (for example, but not exclusively, a Community Heating scheme). There is particular opportunity in new build, and in social housing. Third, a household model, where energy suppliers, contractors or equipment suppliers may evolve their offering to include energy efficiency and micro-generation. Advice on setting up an ESCO in the UK context has been provided by the legal firm, Brodies [29].

Models which provide for single technology investments like CHP or wind, usually have a simpler purpose and structure with both activity and legal framework confined to a lease for the land on which the asset sits, and stopping at the point power and or heat is exported to the site via a meter (though there are ways of sharing risk). These single technology models have been much more common in the UK to date, and this is now explored.

Experience with off balance sheet finance in the UK

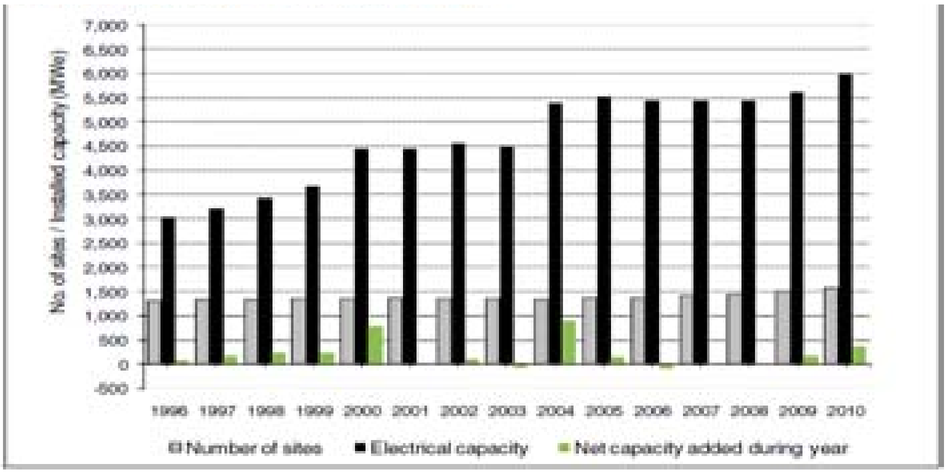
Combined Heat and Power using a range of fuels

Combined heat and power (CHP) is the simultaneous generation of usable heat and power, usually electricity, in a single process. CHP is well documented in Government Statistics [30] and has been explored elsewhere by this author [31]. Heat is used in meeting space or process heat needs. Instead of 30-50% efficiency of power only generation, CHP can achieve 70-90% efficiency. CHP has seen an average 5% growth p.a. over the last 15 years but with significant variation annually, because of policy and market evolution, and in part because of individual large projects commissioned on industrial sites.

Around 1100 out of the total 1600 schemes are in buildings, with the other 500 meeting process needs in industry. However, in terms of capacity, 95% of capacity is in industry. Around 70% of the fuel used in CHP schemes currently is natural gas, with around 6% renewable fuel and the remainder industrial co-products, byproducts and wastes. However, there is a large untapped market for other fuels, including anaerobic digestion of wastes (especially in the food and drink, distribution, and public sectors)/ these schemes would produce a digestor gas for burning in CHP, either alone or alongside natural gas to stabilize combustion and match heat and power production to site needs. Most of the 30-odd scheme developed to date are on a self-finance basis not on an off balance sheet basis, but these were ‘early adopters’ and the larger opportunity is in more cautious organizations via off balance sheet investment.

There is also an option for solid wastes especially wood and waste paper in the distribution and waste sectors. This may be for heat or for heat and power, though the technologies associated with power generation from solid fuels at small scale, including pyrolysis and gasification, are not well proven and anecdotal but real market experience suggests that the UK Environment Agency is very risk averse and a major barrier to development. With waste based schemes there is a gate-fee and landfill tax avoidance benefit, as well as an income from heat and power. Though, when schemes are embedded in a site they are very dependent on the availability of feedstock as well as a customer for the heat and power.

Installed UK CHP Capacity



Source [30]

ESCO arrangements for CHP are discussed by DECC and can vary widely [32]. The basis of an agreement of this type is the transfer of CHP plant capital and operating costs, together with all the technical and operating risks of CHP, from the end-user to the ESCO contractor. The variables to be resolved in a contract include:

- Who will operate the plant on a day-to-day basis and, therefore, bear the performance risk?
- What happens if the site increases or reduces its need for heat and power, or closes completely?
- Who will own the plant at the end of the initial agreement period of 10-15 years and at what ongoing cost?

As well as supplying heat and power to the company at agreed rates the ESCO contractor may also take responsibility for fuel purchase and for other on-site energy plant. In some cases the ESCO contractor may ‘oversize’ the scheme to both meet the heat requirement of the company and produce significant surplus electricity that can be exported and sold.

Any transaction with an ESCO contractor still involves a long-term commitment by the site. The sites audited accounts should contain a summary of this commitment. Evidence will also be needed to satisfy the site's auditors that the arrangement is an operating lease and not a finance lease. If ownership transfers to the site is implied or stated in the contract, the arrangement must appear on the site's balance sheet.

There has been a lot of takeover and merger activity in this market as it has passed through a difficult period and providers in this market currently include Ener-g (who have acquired Nedalo and Switch2), Utilicom (now part of Cofely), Cogenco (part of Dalkia), and Vital Energi (part of SSE). Most of these providers specialise in gas based schemes though Dalkia has a portfolio of waste management projects. There appears to be an opportunity for new entrants specialising in other fuels and processes like AD based CHP.

Wind on industrial and commercial sites

There is a growing portfolio of wind on industrial and commercial sites. Some of these are small and meaningless in energy and carbon and cost saving terms. Wind over 500kW is summarised below.

Wind on industrial sites in the UK

Summary	number of schemes	Capacity (MW)	No of turbines	% capacity
Operating	25	69	41	33%
Consented	14	61	32	30%
In planning	9	37	6	18%
In development (as far as is known)	5	10	7	5%
refused or abandoned after gaining consent	11	29	32	14%
	64	206	118	100%

(Source: Authors own analysis of a range of sources)

Common features of schemes are as follows:

- There is a relatively high success rate in terms of gaining planning consent compared to wind in general (circa 80% for smaller projects typical of industrial sites, compared to circa only 20% in open country, based on statistics from Renewables UK [33]).
- They are in sectors such as Food, distribution, the car industry, Chemicals, dockyards or ports as well as some in the Public Sector.
- Schemes are more likely to be in the northern half of England and across Scotland, in a higher wind regime. However, industrial sites see a lower than usual wind regime because of the 'Roughness Factor' of the landscape causing reduced wind speeds as well as turbulence.
- They can be located onsite or on land adjacent to the site, as long as they are supplying onto the customers side of the meter. This has a commercial benefit in that it saves the cost of Distribution Use of System Charges (DUoS) of around 2ppkWh plus around 0.5p from the fact that renewable generation is exempt from the Climate Change Levy.
- A 25 year Lease is needed and a Power Purchase Agreement (PPA) is based on units sold and a price (ppkWh) mechanism often linked to market prices.
- Schemes can displace a quarter to two thirds of site electricity demand. To go higher is hard because of the variable nature of wind. Often when schemes are generating at full power they are exporting.
- Most of this is by two companies, Ecotricity and Wind Direct (with my own company, Susenco a new market entrant) and though these companies are providing an off-balance sheet solution, they do not see themselves as ESCOs in any way. There are only a small proportion of schemes which are self-financed.

PV on industrial and commercial sites

In the UK there was a lot of interest in PV on rooftops and carparks (eg in major retail parks, distribution centres and factories), following US and European models. However, this market has been heavily constrained following major Feed In Tariff reviews [3]. There is still an opportunity in future given a mature and stable Feed In Tariff framework. A key issue already explored above is the leasehold relationship and whilst this is an issue for a range of technologies, the issue is most pronounced for technologies with long paybacks, where the payback is more likely to extend beyond the life of the lease. Nowhere is this more true than for PV because of its long payback time even with Feed In Tariff support.

Energy efficient refurbishments

Whilst there is private sector commercial and industrial activity, the major investment is concentrated in the public estate and in London under the RE:Fit and LEEF programmes discussed above.

The UK Government achieved an average 13% cut in emissions (with cuts varying from 10-20%) in its own buildings (covering 300,000 civil servants in 300 buildings) in 1 year. Whilst much of this was simple measures not necessarily involving ESCOs, the next stages might. It is now aiming for 25% saving in all civil and operational estates by 2015 [34], [35].

RE:FIT is targeting 600 public buildings and already has a pipeline of 300 or so. The reduction in energy bills and the carbon footprint of buildings is achieved by appointing an energy service company to undertake energy efficiency measures in buildings and to guarantee a set level of energy savings under an Energy Performance Contract (EPC). Unlike traditional public building improvement programmes, a whole group of buildings can be offered up for retrofitting in one go, allowing energy services companies to achieve economies of scale. The model does not need to impact on existing facilities management and energy supply contracts. However, where they can be combined, it will streamline the operational phase, particularly monitoring and verification requirements [12].

Buyers initially prepare a Project Brief that identifies the buildings concerned (including building data, bundling opportunities and the energy saving aspiration). A mini-competition is then run by the Buyer to select an ESCo from the framework panel. The Buyer can request varying levels of detail from the ESCos as part of the bidding process, ranging from a Desk Top Audit to a full Investment Grade Proposal, within their procurement guidelines. Once the Buyer has selected the preferred supplier, the works are delivered and then subjected to ongoing monitoring, verification and reporting so that energy savings can be proven [12].

The LDA is currently in the process of establishing the London Green Fund to fund investment in decentralised energy and energy efficiency projects through the JESSICA fund. This fund will provide loan capital to public sector bodies who do not currently have access to funds to pay for retrofitting which will then be paid back using the guaranteed energy savings. The aim is to achieve 20% savings in public buildings, investing £20m this year, and £70m by end 2015.

These programmes are causing a new energy services industry in the UK. They are new entrants to the energy services market but have an established base in a related market. They come from a construction background (like Balfour Beatty), an energy background (like EDF), a building services background (like HurleyPalmerFlatt) or an outsourcing and Facilities Management background (like MITIE).

Equally interesting is who is <u>not</u> yet engaged in this market. For example, there are not yet many European or US ESCOs entering the UK in a meaningful way. There are many UK based mechanical and electrical contractors with the engineering skills, but not the imagination, selling skills or contractual experience who are not yet in this market (like Laing ORourke). However, there is still much room for market development. It would also seem opportune for major commercial property Services companies (like Savills) to enter this market on the basis that many organisations have been rationalizing their portfolio, or going through a major sale and leaseback process, and it would be a coherent business model to first rationalise your portfolio, or buy space then think about services as part of the acquisition and management process. Also, given the multiple skillsets needed, obvious models for growth include partnering in a consortium, or acquisition activity. Partnerships include ARUP working with Skanska. Acquisitions include MITIEs acquisition of energy purchaser Utilyx which puts their energy purchase and supply power on a par with an energy supplier, yet clearly they retain their Facilities Management and outsourcing skill sets. This is a powerful move.

Analysis and conclusions

Compare and contrasting of business models

There is a huge difference between financing energy generation and energy efficiency

- Third party financed energy generation is often a single technology (either CHP or wind or PV on any given site) versus multiple technologies for energy demand management on a given site (which may include fabric measures, heat supply networks and emitters, cooling, controls, lighting, process control equipment etc.)
- Energy generation takes place on discrete locations, either outside the buildings, or in a contained space, whereas energy efficiency is a diffuse set of assets with little ability to access or recover assets if there is a contract default. This makes energy efficiency much more difficult to bank finance.
- Energy generation has a clear charging mechanism (kWh of electricity or heat supplied) which has been the basis of metering technology and billing for many years. The basis of measuring energy savings against a baseline as a basis for charging is harder to convey and understand, even with tools available such as the IPMVP measurement and verification protocols [36].
- For the above reasons bank borrowing is relatively available for power generation, whereas energy efficiency investment needs on balance sheet finance at least in the first instance (it might later be re-financed to grow new installations). Entry into energy efficiency therefore needs a large existing balance sheet which means entrants can move sideways from related activity, but it rules out start-ups.
- There is a very different risk profile for the different opportunities. CHP is predominantly a commercial and operational risk. Key issues are the relationship between gas and electricity prices (the so-called spark spread), and an occupier to need heat and power for a sufficient period to justify a contract and to want to enter long term agreement. Wind (even for small projects on industrial sites) is a high planning risk. There is a relatively high resource risk around wind availability because of the effect of the industrial landscape on wind speed and turbulence, as well as a natural variation in generation year to year of +/-20% which can cause cash flow risk. With energy efficiency, there is risk around prediction, measurement and base lining, take back (whether benefits are taken as increased service or reduced consumption) and around change of use or physical alterations to the property by the landlord.
- Partly as a consequence of differing risk profiles, there are different returns available and different returns expected. Wind might have a venture capital rate of return, whereas energy efficiency may be closer to a pension fund rate of return. PV and CHP are uncertain but lie in between.
- Market players can be very different. Wind and PV is a specialist investment but with a mature supply chain. It can be delivered by a relatively small investor (like Susenco). CHP takes more management and maintenance and needs a larger player. Energy efficiency needs a large balance sheet to finance it. Interestingly there is relatively little cross over between the market players.

The size of the market for third party solutions

The size of the market for carbon reduction using these three approaches is very large in future, but very constrained now by risk aversion, a lack of vision, understanding, models, marketing and change management skills. Government is tinkering around the edges, including on its own estate, but could change the nature of markets as a major challenge in delivering a low carbon future. Taking different sectors in turn:

- Public. For public sector emissions, the research estimated emissions from the public sector in England, including available transport data, was 16.7MtCO_2e, with an associated cost of approximately £2.5bn for building energy and £1.2bn on owned-vehicle fuel. Across the public sector estate in England, an investment of £1.66bn for cost-effective carbon reduction could deliver annual carbon and cost savings of 3.4MtCO_2e, and £729m (21 MtCO_2e and £4.9bn over the lifetime of measures), or a marginal abatement cost of -£155/tCO_2. This marginal abatement cost varies across different parts of the public sector (note to convert from England to the UK, multiply by around 1.06) [35].

- Commercial buildings. There are 2million commercial buildings which account for 17% of UK carbon emissions (excluding the public sector), with industrial energy use around another 20% of UK CO2 emissions. Opportunities to refurbish the UK non domestic building stock is explored in more detail by the Carbon Trust [37].

- Households. 26million homes account for around 27% of UK carbon emissions. The easiest sectors to tackle from an energy services perspective are those where decisions are made in or on behalf of groups of households, i.e. social housing (around 4.6m homes), flats (around 3.2m properties), and new builds (between 1-200,000 p.a depending on market conditions) though there are overlaps between these groups [38]. The other maturing market is community organizations, which share ideas and values (they are self-referencing), evaluation methods, and procurement. Whilst there are many such groups, one example is Low Carbon West Oxford [39].

Boardman has published a strategy for energy use in all buildings in the whole UK results in zero carbon emissions by 2050, covering all 26 million homes and 2 million non-domestic properties [40].

Policy recommendations

The first and most important issue is the realization that with very challenging carbon targets on the one hand, and significant barriers to uptake for embedded generation and energy efficiency on the other, third party finance provides a way through for business. If Government realizes how key third party solutions could be to delivering on its targets, it can open the way for them. Government must realize it can be a market maker, first by way of creating exemplars in the Government estate, but in more importantly in how it sets market rules. Beyond providing examples in its own estate, third party solutions need embedding in policy design. For example:

- The UK Governments Green Investment Bank is at an early stage [41] and could take upon itself a clear role in supporting the expansion of technologies and providers in the market delivering third party solutions.

- The idea has been mooted of applying building regulations on existing build, at the point of sale or lease [40]. If retrofit is <u>required</u> (rather than just offered) how is it to be financed in difficult circumstances? The Green deal has opened this opportunity up, but there is little practical experience. Government has a key role in providing guidance and case studies.

- UK Feed In Tariffs were designed to deliver a return on investment of 5-8%. This is too low in many sectors where management would be looking for higher returns from commitment of internal capital and time resources, and certainly not sufficient to reward both a landlord and a third party provider. To deliver large scale uptake therefore needs a better understanding of barriers to development and solutions for overcoming them. It may be more expensive to deliver than Government has currently allowed.

- There is a role for planning policy on new power projects. If combustion based power stations were only able to get consent if they were combined heat and power (as well as carbon capture and storage), it would incentivize power generators to find ways of capturing and supplying the heat as well as the carbon, driving them to work with large industrial heat users to deliver off balance sheet solutions for those heat users. And planning policy on wind power and energy from waste could clearly indicate a presumption in favour of schemes on industrial sites (where the landscape is already man made and where background noise would mask turbine noise).

- Too much of UK Government policy is made by obligations on existing market players (eg the Renewables Obligation, and the Energy Company Obligation which finances Green Deal). This reinforces the dominance of the existing players and makes new market entry very difficult. Yet it is very easy to be lobbied by large organisations with strong policy and lobby teams, and hard to consult with organizations like start ups or small businesses without resources to lobby. Government needs to develop a style of policy making which continually creates opportunity for new market entry.

Ultimately to achieve the targets set, a complete new market framework which moves power from the hands of a few large utility companies and creates a market of literally millions of embedded generators deploying a range of technologies. This means measures which make small generation more competitive with large centralized supply. It also means a market framework which makes demand reduction more competitive with energy supply (drawing on what the US market used to call Integrated Resource Planning).

Final conclusions

Off balance sheet is a way of giving the task to someone with the skills time and capital to deliver. If the UK carbon target is to be met, and in a timely way, it is key for Government to realize the importance of off balance sheet solutions and be a market maker in enabling them, not only by way of creating exemplars in the Government estate, but in how it sets market rules. If this happens, the market place for energy supply and energy efficiency, as well as the market for buildings will become unrecogniseable. New entrants (especially in energy efficiency, but less so in power provision) will tend to be from but existing businesses in adjacent business fields rather than start-ups. There is likely to be significant partnering and acquisition activity.

References

[1] DECC (2008) *Climate Change Act 2008* Department of Energy and Climate Change, London downloadable from www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx

[2] DECC (2011) *Electricity Market Reform White Paper*. Department of Energy and Climate Change, London. Downloadable from www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/emr_wp_2011.aspx

[3] DECC website *Feed In Tariffs*. www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/feedin_tariff/feedin_tariff.aspx

[4] DECC website *The Renewable Heat Incentive.* Department of Energy and Climate Change, London. www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx

[5] DECC website *The Green Deal.* Department of Energy and Climate Change, London. www.decc.gov.uk/en/content/cms/tackling/green_deal/green_deal.aspx

[6] DECC website *Carbon Reduction Commitment.* Department of Energy and Climate Change, London. www.decc.gov.uk/en/content/cms/emissions/crc_efficiency/crc_efficiency.aspx

[7] DCLG website *Planning Policy*. Department of Communities and Local Government London www.communities.gov.uk/planningandbuilding/planningsystem/planningpolicy/

[8] DCLG website *Building Regulations* Department of Communities and Local Government London www.communities.gov.uk/planningandbuilding/buildingregulations/buildingregulationschanges/

[9] DEFRA website *The Market Transformation Programme* Department of Environment Food and rural Affairs http://efficient-products.defra.gov.uk/

[10] GLA Website *Delivering London's Energy Future* Greater London Authority www.london.gov.uk/who-runs-london/mayor/publication/climate-change-mitigation-energy-strategy

[11] GLA website Greater London Authority, www.london.gov.uk/priorities/environment/climate-change/energy-efficiency/homes-energy-efficiency-for-tomorrow

[12] GLA website Greater London Authority www.london.gov.uk/priorities/environment/climate-change/energy-efficiency/buildings-energy-efficiency-programme

[13] GLA website Greater London Authority www.london.gov.uk/priorities/environment/climate-change/low-carbon-zones

[14] GLA website Greater London Authority http://www.london.gov.uk/priorities/environment/climate-change/decentralised-energy

[15] EIB Website ELENA http://www.eib.org/products/technical_assistance/elena/index.htm

[16] EIB Website JESSICA http://www.eib.org/products/technical_assistance/jessica/index.htm

[17] EEEF website European Energy Efficiency Fund http://www.eeef.eu/

[18] Golove W., and Eto J., (1996) *Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency*. Lawrence Berkeley National Laboratory paper number LBL-38059. Downloadable from http://eetd.lbl.gov/ea/emp/reports/38059.pdf

[19] **Hinnells M, Bright S, Langley A, Woodford L, Schiellerup P, Bosteels T** (2008) *The Greening of Commercial Leases* in Journal of Property Investment and Finance V 26, No 6 2008. pp541-551. Emerald 1463-578X.

[20] Hinnells M (2008) *Greening the Commercial Leasehold Relationship* in a special issue on green leases, The Conveyancer, pp Issue 6 2008. Sweet and Maxwell ISSN 0010-8200.

[21] BBP (2009) Green Lease Toolkit. Working together to improve sustainability. Better Buildings Partnership with the GLA (Greater London Authority) http://www.betterbuildingspartnership.co.uk/working-groups/green-leases/green-lease-toolkit/

[22] International Financial Reporting standards IFRS website http://www.ifrs.org/IFRSs/IFRS.htm

[23] http://www.investopedia.com/terms/g/gaap.asp

[24] European Standard Accounting ESA95 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:ESA95

[25] Sorrell S., (2005) The economics of energy service contracts Tyndall Centre for Climate Change Research Working paper 81. Can be downloaded from http://www.tyndall.ac.uk/sites/default/files/wp81.pdf

[26] Bertoldi P., Boza-Kiss B,Rezessy S., (2007) *Latest Development of Energy Service Companies across Europe - A European ESCO Update* -. Institute for Environment and Sustainability, Joint Research centre of the European Union (JRC). Report number EUR 22927 EN-2007. Can be downloaded at: http://energy.eu/publications/LBNA22927ENC_002.pdf.

[27] Satchwel A., Goldman C., Larsen P., Gilligan D., and Singer T., (2010) *A Survey of the U.S. ESCO Industry: Market Growth and Development from 2008 to 2011.*Lawrence Berkeley National Labopratoryreport numberLBNL-3479E. Can be downloaded at: http://eetd.lbl.gov/ea/ems/reports/lbnl-3479e.pdf.

[28] Bertoldi P, Hinnells M, and Rezessy S (2006) Liberating the power of Energy Services and ESCOs in a liberalised energy market. [PDF: 204KB] Paper to EEDAL 06 (Energy Effiicency in Domestic Appliances and Lighting, London June 2006.

[29] Brodies LLP (2007) *Making ESCOs Work: Guidance and Advice on Setting Up & Delivering an ESCO.* Brodies LLP Solicitiors for theLondon energy Partnership. Can be downloaded at http://www.lep.org.uk/uploads/lep_making_escos_work.pdf

[30] DECC (2011) Digest of UK Energy statistics (DUKES) Chapter 6 Combined heat and power http://www.decc.gov.uk/assets/decc/11/stats/publications/dukes/2308-dukes-2011-chapter-6-chp.pdf

[31] Hinnells, M. (2008) *Combined heat and power in industry and buildings*. Energy Policy 36 (2008), pp. 4522-4526 DOI information: 10.1016/j.enpol.2008.09.018

[32] DECC website Combined Heat and Power http://chp.decc.gov.uk/cms/off-balance-sheet/

[33] RenewablesUK (2011) State of the Industry Report, Onshore and Offshore Wind: A Progress Update, October 2011 http://www.bwea.com/pdf/publications/SOI_2011.pdf

[34] DECC website what is the Public Sector Doing? http://www.decc.gov.uk/en/content/cms/tackling/saving_energy/what_doing/what_doing.aspx

[35] http://www.decc.gov.uk/assets/decc/11/tackling-climate-change/saving-energy-co2/2261-camco-report-public-sector-emissions.pdf

[36] EVO (various) International Performance Measurement and Verification Protocol (IPMVP). Downloadable from http://www.evo-world.org/

[37] Carbon Trust (2010), Building the future today, Carbon Trust

[38] DECC (2012) English Housing Survey Headline Report 2010-11. http://www.communities.gov.uk/documents/statistics/pdf/2084179.

[39] Low Carbon West Oxford http://www.lowcarbonwestoxford.org.uk/index.php

[40] Boardman B (2012) Achieving zero: delivering future-friendly buildings. Report from the Environmental Change Institute University of Oxford. Downloadable from http://www.eci.ox.ac.uk/research/energy/achievingzero/index.php.

[41] BIS Website *UK Green Investment Bank* Department for Business Innovation and Skills, London http://www.bis.gov.uk/greeninvestmentbank

Building up a market for energy contracting for commercial buildings in Upper Austria

Christiane Egger

Deputy Manager, O.Ö. Energiesparverband

Abstract

Upper Austria was one of the first regions in Europe to develop a dedicated programme for energy contracting. The regional "Energy Contracting Programme" supports energy efficiency projects and investments in renewable energy technologies and the initial focus on the public sector was extended to businesses. One focus area of the programme are commercial buildings which are supported by advice services and financial incentive.

The market development activities are co-ordinated and managed by the O.Ö. Energiesparverband (ESV), the regional energy agency of Upper Austria.

Using a well-targeted approach, the O.Ö. Energiesparverband (ESV) managed to establish a functioning Energy Contracting market in Upper Austria with more than 100 Energy Contracting projects already carried out successfully. About 27 Million Euro investment was triggered in recent years.

Background

Since the mid-90s, the government of Upper Austria has prioritised energy efficiency and renewable energy. Renewable energy currently supplies 34% of the total primary energy demand in the region. The share of renewables in the energy mix was achieved through comprehensive regional energy action plans that laid the foundation for more than a decade of steady progress. Building upon the success of its policies to date, Upper Austria has set a target to meet 100% of its electricity and space heat demand by renewable energy sources. and to reduce energy consumption for heating by 39% and CO_2 emissions by 65% by 2030.

To achieve its ambitious goals, Upper Austria has developed policy packages for different target groups. These packages consist of financial incentives (mostly investment grants), legislation to mandate installation obligations, and promotional activities (energy advice, outreach campaigns, training, etc.). The different types of support mechanisms can be thought of, respectively, as carrots, sticks, and tambourines. The ESV is in charge of implementing many of these programmes and providing related services.

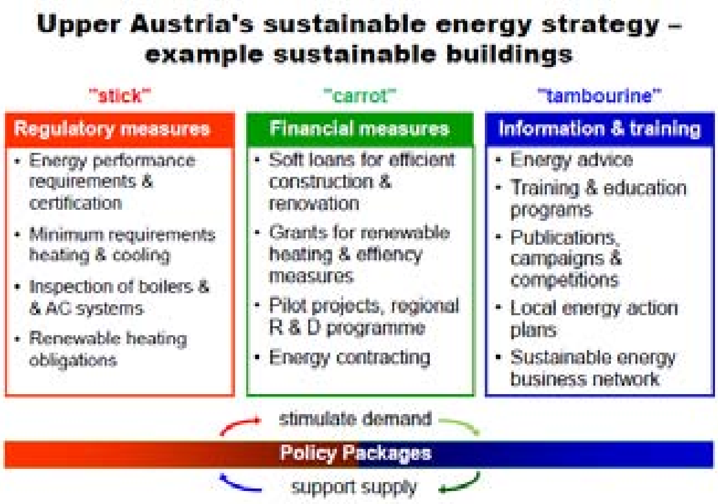


Fig.1

The ESV also manages the "Okoenergie-Cluster", the network of renewable energy and energy efficiency companies in the state. There are currently 160 companies and institutions in the network, which employ more than 7,300 people and generate annual revenues of more than 1.8 billion Euro. The network members represent the full spectrum of sustainable energy products and services and high-efficiency building technologies. In recent years, companies in these fields have experienced strong growth and have added more than 500 new in-state jobs.

Approach

One approach to overcome the challenge of high upfront investments (compared to lower operation costs) of renewable energy installations and energy efficiency investment is the instrument of energy contracting. Here an ESCO (energy service company) invests in energy efficiency measures (energy performance contracting) and/or in renewable energy installations located within the premises of a company and sells heat to the owners/users of the buildings at an agreed price (supply contracting).

The basis of such an energy contracting project is a contract between the ESCO which states the main conditions and rules for a longer-lasting partnership. Contract duration often is between 5 and 15 years. The ESCO is a specialist in energy efficiency and/or renewable energy and the client does not need to concern himself with investment, planning, fuel supply and daily operation.

However, interesting as this business model is, markets are hard to establish.

O.Ö. Energiesparverband has tried to overcome the market barriers for contracting by implementing a combination of financial incentive and awareness raising & information programme. Wide-ranging awareness raising activities targeting the "supply side" (i.e. ESCOS – the suppliers of energy services) as well as the "demand side" (e.g. companies as clients) are the most crucial factor in this development. Continuous information and awareness raising activities support programme implementation. Another innovative aspect of the Upper Austrian Energy Contracting Programme is the standardisation of procedures. Applying for financial incentive is also relatively easy.

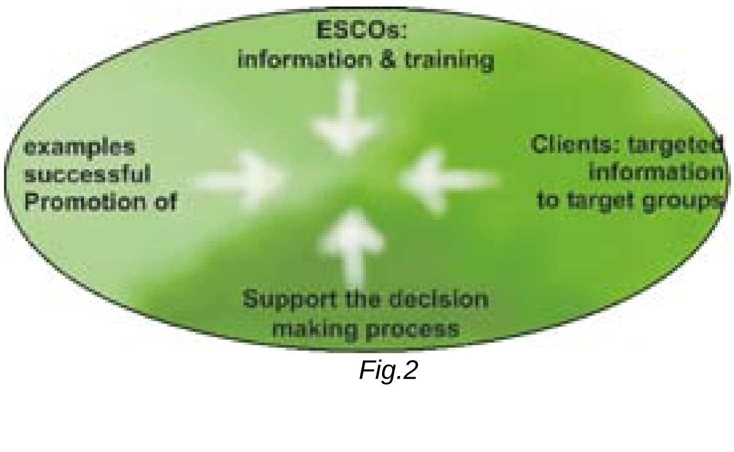


Fig.2

The Upper Austrian Energy Contracting Programme

The Upper Austrian Energy Contracting Programme triggered a market for energy contracting and more than 100 projects were already realised. With the support of the programme, the first contracting projects were already implemented in 1999. The programme combines a financial element (subsidy) with comprehensive information for the ESCO and for the client.

A balanced approach was carried out to help both sides - the ESCO and the clients, which are municipalities and businesses. Especially the energy advice given in the frame of the programme by the regional agency (O.Ö. Energiesparverband) helped very much to establish confidence in the contracting instrument. It is also very helpful for the ESCOs to get support and advice when implementing their first contracting project, for example, the contracts were reviewed and critical questions discussed with both contract partners. ESCOs and clients applying for the support are guided by the O.Ö. Energiesparverband and are therefore able to benefit from the experience of earlier projects. Especially for commercial buildings projects, it was very helpful to benefit from energy contracting projects already implemented in the public sector.

The combination of financial incentive with an information element (advice from experts) is one of the key factors for achieving successful implemented projects and for establishing a broad contracting market in the region. The aim of the support programme was not only to financially support contracting projects, but also to improve the quality of the services offered by the ESCO. This quality approach turned out to be very successful, a survey among contracting clients who implemented a contracting project showed that the far majority of them is very satisfied with the project.

The quality approach was also very beneficial for the ESCOs and helped to make them more professional and to ensure high quality of their services. Presently a number of ESCOs offer their services in Upper Austria. The O.Ö. Energiesparverband offers on its website a service which present the most active ESCOs. In order to be named on the website, the ESCO has to deliver quotations of references and the contract is checked by O.Ö. Energiesparverband. Presently 15 ESCOS are listed and in total more than 30 ESCOs are established which offer services in Upper Austria.

ESCO contracts

For successful implementation of energy contracting projects it is necessary that the respective contract lays down rules for all relations between the client and the ESCO which are resulting from the project. The crucial points to be taken into account within a contract are among others:

- explicit statement of the contract duration
- what to be done in the event of damage or loss (maintenance?)
- what to be done in case of bankruptcy of a contracting party?
- what to be done if the designated use of the building changes?
- are there provisions for changes of energy prices foreseen?
- guaranteed energy savings and provisions for the allocation of guaranteed cost savings as well as consequences if the guaranteed savings are not met
- passing of the risk and the property
- what to be done if the building is sold?

In addition to these minimum requirements of a contract, the Upper Austrian support programme requires the following criteria for granting financial support:

- the ESCO needs to proof that he/she has the necessary technical skills
- the investment has to be at least 40,000 Euro
- the financial reliability of the ESCO and the client have to be proven
- a detailed energetic analysis of the project has to be carried out including a list of possible measures and a cost-benefit calculation
- the project duration shall not exceed 10 years very much
- beneficiary of the financial support is the client. The support has to be used to reduce the payment of the client to the ESCO. A written agreement about this has to be delivered.

Programme innovation

The Upper Austrian contracting programme does not support the retrofitting of buildings as such, but the business model contracting. It is the first and so far only contracting programme in Austria.

Another innovative aspect of the Upper Austrian Contracting programme is the standardisation of procedures. Applying for a Contracting subsidy is fairly simple.

Feed back from ESCOs and other market actors as well as international experience is permanently included in the programme activities and used for further programme development.

Success factors & benefits

Energy Contracting has a number of benefits, for example:

Benefits for building owners/users:

- improvement of building infrastructure (heating system) without the need of using own capital
- predictable heating costs for the contract duration
- professional planning and implementation of the system by a specialist
- no functionality risk of the installation
- no maintenance efforts
- image benefits

Environmental & society benefits

- reduction of CO_2 emissions
- use of local fuels instead imported fossil fuels with related economic and employment benefits

Based on the experience of recent years, the following success factors can be outlined:

A qualified ESCO:

- has a list of references and is able provide proof of its financial standing
- prepares the project well and provides a clear cost-/benefits analysis
- involves and trains buildings staff and users
- proposes a well structured contract which also includes provisions for "difficult" situations (e.g. bankruptcy, changes of ownership etc.)

A good project preparation

- it is important to define the services of the ESCO very well in the preparation process which also allows for a better comparison of the different offers
- a requirement in a call for tender can also be that the ESCO uses wood from local sources (which tends to increase the image and the acceptance of the project).

Examples

More than 100 energy contracting projects were carried out successfully, here are a few examples:

Table 1: Examples energy contracting projects for commercial buildings in Upper Austria

Rosenbauer International retrofitting project (optimisation of the heating system, heat recovery, peak load management) savings: 53,500 Euro/a, 309 t CO_2 reduction/a investment: 365,000 Euro contract duration:6.5 years	
Schachermayer Großhandel energy efficiency measures (control devices, circulation pumps, etc.) savings: 970,000 kWh/a, 38,771 Euro/a investment: 151,000 Euro contract duration: 4 years	
Fronius biomass heating supply for the whole company site 1,200 + 350 kW wood chips boiler investment: 556,088 Euro contract duration:15 years	
Strasser Steine biomass heating supply for the company site (office, production hall, storage hall) 550 kW wood chips boiler investment: 150,000 Euro contract duration: 15 years	
Feriendorf Obertraun new constructed tourist village with 46 buildings (75 apartments) 390 kW wood chips boiler investment: 974,686 Euro contract duration: 20 years	

Mühlviertler Alm Biofleisch biomass heating supply for the company site 150 kW wood chips boiler investment: 42,000 Euro contract duration: 10 years	

Results & conclusions

Using a well-targeted approach, O.Ö. Energiesparverband managed to establish a functioning Energy Contracting market in Upper Austria with more than 100 energy contracting projects already carried out successfully, an increasing number in commercial buildings. About 27 million Euro investment was triggered in recent years.

Regional and local energy agencies or other bodies can significantly contribute to a contracting market development by offering the following services. The crucial points for a successful support of the contracting market development are:

- "in-house know-how": building up know-how within the organisation at a first step
- "explain, explain, explain": the contracting concept as well as the concrete implementation possibilities need significant and continuous efforts in explanation
- providing targeted advice at all project stages
- establishing standardised procedure.

References

[1] Dell G.: *Die Umsetzung des OÖ. Energiekonzeptes.* Berichtsjahr 2010 (Linz, Austria, April 2012). Can be ordered from www.esv.or.at

[2] Dell G.: *Energiezukunft 2030. Die oberösterreichische Energiestrategie* (Linz, Austria, June 2009).Can be ordered from www.esv.or.at

[3] Egger C., Öhlinger C.: *Biomass heating in Upper Austria. Green Energy, green jobs* (Linz, Austria, July 2010). Can be ordered from www.esv.or.at

[4] Egger C., Öhlinger C.: *Carrots, Sticks and Tambourines: How Upper Austria became the World's Leading Solar Thermal Market* (Linz, Austria, July 2010). Can be ordered from www.esv.or.at

[5] FOREST: *Partnerships for Success* (2010). Can be ordered from www.forestprogramme.com

How to Develop A Sustainable Financing Markets for the Promotion of Energy Efficiency in Building Sector Towards Low Carbon Society? Case of Turkey

Ebru Acuner, Sermin Onaygil

Energy Planning and Management Division, Energy Institute, Istanbul Technical University

Abstract

In the whole over the world, it could not be possible to talk about a sustainable future without mentioning energy efficiency in buildings. However, the crucial point in that issue is financing. Especially for developing countries, lack of diversified financial instruments, even without any awareness, is one of the main obstacles. In such an environment, a question coming to mind that how could be possible to have a reliable ESCO market formation?

In case of Turkey, first of all, the current legal framework targeting financing of building sector is aimed to be explained. Afterwards, ESCO activities together with associated financial sources are expressed. Then, some anticipated improvements while in the revision of the legislation are tried to be discussed. Last but not least, alternatives for promoting the ESCOs and also different financial mechanisms, which could be applied to the national conditions of Turkish market are summarized, keeping in mind that every ton oil equivalent (toe) of energy saved can result in bulk of money in any pocket towards low carbon future or society.

Introduction

According to newly announced (25 February 2012) “Energy Efficiency Strategy (2012-2023) for Turkey”, between 1998 and 2008, the increase in annual total energy consumption is 3.81%, in the industrial sector 3.56%, in residential buildings 3.49%, in the transport sector 4.07%, and in commercial buildings 7.44%, which is almost two times the average [1]. In case of annual total electrical consumption, this rate is about 7-8% as on average. While issuing the statistic with regard to electricity, Turkish Electric Distribution Company (TEDAS) classifies the building sector as residential, governmental and commercial buildings. For example, from the last statistics in 2009, electricity consumption shares of residential, commercial and governmental buildings 25%, 15.9% and 4.5%, respectively, constituted 45.4% in total [2].

On the basis of 2010 general energy balance table, among all end-use sectors, the building sector is one of the important players in Turkey, which has a share of 35% and 50% in total energy and electrical energy consumptions, respectively [3]. This also shows that from 2009 to 2010 the electrical energy consumption of whole building sector increases from 45.4% to 50% in a year. In case of commercial/public buildings, although there is no such differentiation in total energy consumption, for total electrical consumption, they constitute about 21%.

For the building sector, with approximately 30% energy saving potential (according to the results of Twinning Project entitled “Improvements of Energy Efficiency in Turkey”), development of legal framework was started at 2007 [4,5]. Figure 1 represents up-to-date legislation concerning the building sector with their enforcement dates. In this scope, the first driving force is Law on Energy Efficiency (EE Law). Afterwards, main regulations on efficient utilization of energy sources and energy (En-Ver) (October 2008), building energy performance (BEP) (December 2008), and sharing of heat expenses (April 2008) were enacted under the framework of the Law. Moreover, more specific regulations related to efficiency requirements of hot water boilers with liquid or gas fuel, household air conditioners, and fluorescent lighting ballasts were published. Afterwards, due to need of proper adaptation to current conditions, such as increase in the standard values required, and for the sake of proper implementations, firstly energy labeling of household air conditioners (June 2007) and BEP was revised in April 2010. Furthermore, there are also revisions under the framework of EU Eco-design directive in terms of other important electrical appliances and lighting installations, such as Notice on Environmental Friendly Design Requirements of Fluorescent Lamps without integrated ballasts, High Intensity Discharged Lamps with their Ballasts and Lighting Luminaries, published in August 2011. Lastly, more recent revision was made on En-Ver regulation in October 2011 (Figure 1).

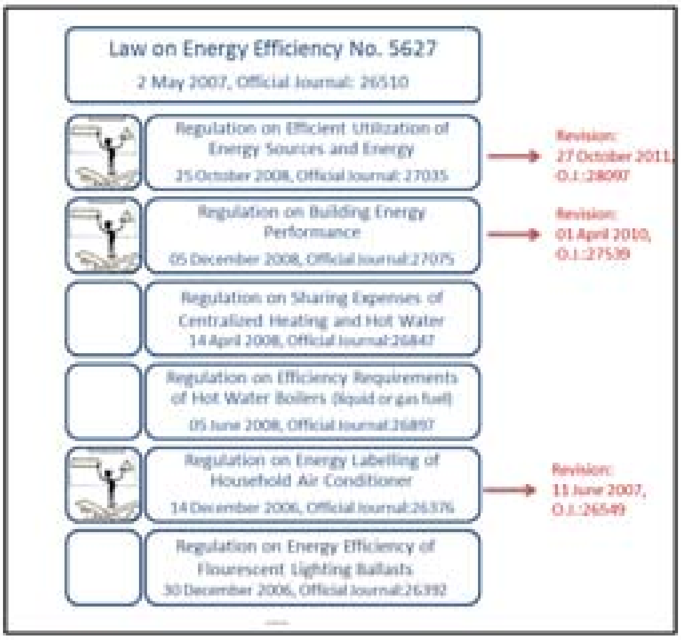


Figure 1. Legislation related to building sector

Fundamental aims of EE Law are to use energy and its main sources efficiently, to reduce energy losses, as well as its costs that affect the national economy adversely and to protect the environment. Considering these aims, the scope of the Law comprises energy efficiency related activities, and implementations for energy production, transmission, distribution and consumption sectors. Regarding building sector, it is stated that the scope is for the commercial / service/ public/ governmental buildings with either total construction area, meaning total m^2 including all common areas as well as basement, entresol and roof and all floors and closed places belonging to building, equal or greater than 20 000 m^2 or 500 tones oil equivalent (TOE) total annual energy consumption [6].

Previously, energy efficiency activities, which concern especially end-use sectors, were conducted only by the General Directorate of Energy Sources Survey and Development Administration (EIE) under the supervision of the Ministry of Energy and Natural Resources (MENR). After EE Law, in order to conduct such activities, a new administrative structure has been established (Figure 2).

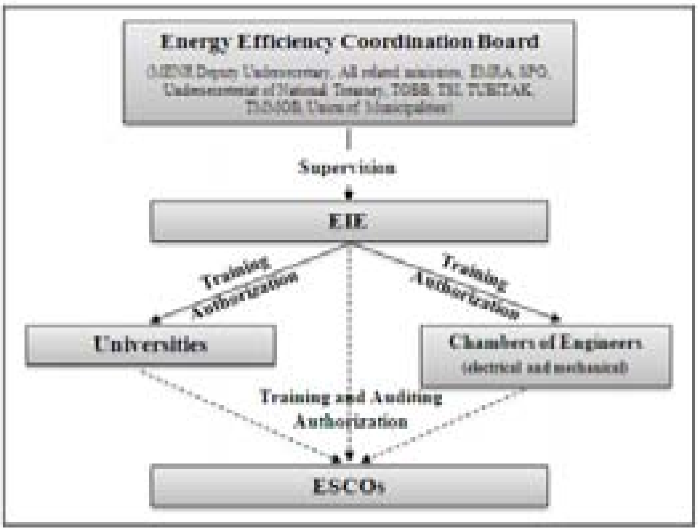


Figure 2. Administrative framework on energy efficiency in Turkish building sector

In this new administrative structure, the authorization with regard to organizing energy manager courses can be given to both universities and specified chambers of engineers (authorized institutions) by EIE, which acts as a secretariat under the supervision of Energy Efficiency Coordination Board (EECB). In addition, either EIE or authorized institutions can give authorizations related to training, auditing, consulting, and implementation activities to energy service companies (ESCOs) and these institutions should provide required laboratory infrastructure especially for the trainings, which will be organized by ESCOs. Both EIE and authorized institutions has been performing training activities since 2009 and after the number of authorized institutions, giving training services, reaches to 10, EIE shall terminate these trainings. However, in 2 November 2011 (Official Journal Number: 28103) by means of Government Order No. 662, EIE was closed and "General Directorate of Renewable Energy" under MENR has been established. Since this time, no additional revisions were the case for this structure but it is highly probable to expect changes not only for the structure but also for the regulations.

In order to explain energy efficiency activities and implementations regarding the building sector, main regulations are listed and briefly described below in the order of their enforcement dates:

- Regulation on "Sharing the Expenses of Centralized Heating and Hot Water" (sharing of heat expenses), which is the first regulation, prepared after the Law, was published on 14 April 2008 (Official Journal Number: 26847). The aim of this regulation is to state provisions and implementations considering the share of heating and hot water expenses among the independent consumers in the existing or newly constructed buildings with centralized or regional heating and hot water facilities. In this scope, the main implementation is the installation and usage of thermostatic radiator valves. The related standard, namely TS EN 215, prepared in 2007, should be taken into consideration for the proper implementations [7].

- In line with the aim of EE Law, regulation on "Efficient Utilization of Energy Sources and Energy" (En-Ver), published in 25 October 2008 (Official Journal Number: 27035) and revised in 27 October 2011 (Official Journal Number 28097), comprises general provisions and implementations on the following topics [8]:

    - Authorization of universities, chambers of mechanical/electrical engineers, and ESCOs for directing and wide spreading energy efficiency services,

    - Implementations with regard to energy management, i.e. responsibilities of energy managers and energy management units,

    - Certification procedure in energy efficiency related trainings,

    - Realization and support of energy efficiency audits, projects as well as voluntary agreements, and demand side management,

    - Increase in energy efficiency also in electrical energy production, transmission, and distribution,

    - Stimulation of waste heat recovery especially in thermal power plant, efficiency increase in street/road lightings, usage of alternative fuels, such as biofuels and hydrogen.

Within the framework of this wide-range scope, the implementations as well as responsibilities of shareholders in the building sector are summarized in Table 1.

Table 1. Provisions for Turkish building sector stated in En-Ver

Implementations	1. Assignments of energy managers: a) Commercial and service buildings having either 20 000 m^2 or more construction area or 500 TOE or more total energy consumption annually and governmental buildings with either 10 000 m^2 or more construction area or 250 TOE or more total energy consumption annually are responsible. b) In order to develop energy management, having TS ISO 50001 certification. 2. Energy Audits and Projects for increasing efficiency: - Performing energy efficiency audits for commercial and service sector buildings with 20 000 m^2 or more construction area and renewing in every 4 years. - Preparing projects that are for implementation of the determined measures after the audits.
Responsibilities	Reporting all energy related consumption information to EIE by the end of March every year. Commercial and service buildings aiming accommodation, health, school, shopping services should inform EIE in every 5 years about the last 3 year annual total energy consumptions.

- The last but not the least regulation namely "Building Energy Performance" (BEP) was enforced on 5 December 2008 (Official Journal Number: 27075) and revised in 1 April 2010 (Official Journal Number: 27539). The major aims of BEP targeting both existing and new buildings are as follows [9]:
    - Preparation of calculation tools, standards, methods and minimum performance criteria concerning energy certification and energy efficiency projects for energy consuming systems of the building, such as architectural design, mechanical, and electrical installations, and lighting.
    - Authorization on building inspection, auditing, and energy labeling.
    - Support of cogeneration and renewable energy applications.
    - Formation and regular update of inventories related to building stocks in the country.
    - Training and awareness activities for the public on energy efficiency.

Under the framework of BEP, main standards that were prepared can be listed as "TS 825 Building Heat Insulation" (revised in 2008), "TS EN 378 Cooling Systems and Heat Pumps" (chain standards between 2001 and 2007), "TS EN 14336 Heating Systems: Establishment and operation of water based heating systems for buildings" (2007), "TS EN 832 Thermal Performance of Buildings: Calculation of energy required for heating purposes in the houses" (2007) and "TS EN 15193 Building Energy Performance: Energy requirements for lighting" (2008). All other related standards with their conjugate European ones are mentioned in BEP and it is stated that if there exists any requirement, the original European standards can be used for the implementation in the annex of the regulation.

Although this regulation was prepared by Ministry of Public Works and Settlement, in 2011 this ministry was joined with Ministry of Environment and titled as "Ministry of Environment and Urban Planning". Hence, all implementations of BEP shall be regulated and monitored by this newly born ministry.

Current energy certification scheme of buildings are presented in Figure 3. As can be seen from this figure, for new buildings, energy certification can be prepared by legal/persons/entities with authorization to give this certificate and also with "Freelance Engineer/Architect" License from chamber of engineers. On the other hand, for the existing buildings, ESCOs having an engineer or architect with certification authorization can prepare the energy certificate. This application has been started for the new buildings from 2011. In case of existing buildings, energy certification will be required after 2017. Although there are ongoing energy efficiency audit studies by ESCOs especially for the commercial buildings, it could not be possible to monitor them. On the other hand, through energy certification scheme (i.e. software called BEPTR), in 2011, totally 5196 certificate has been approved, 89% of which for the new buildings [10]. For the existing ones, the market will improve faster after 2017, as there will be legal penalties on CO_2 to be applied towards low carbon society.

Figure 3. Certification scheme of buildings

Existing Incentives and Programs of the Turkish Government on Energy Efficiency in Building Sector

In current legislation, there are two main incentives stated. The first one is incentive for "energy efficiency projects" and the second is for "voluntary agreements". Both of them are defined for the industrial sector, with total energy consumption equal or greater than 1000 TOE whereas there exist no incentives targeting building sector (Table 2).

As also well-known, ESCOs can be regarded as a financial mechanism for energy efficiency projects through third-party financing. Up to now, totally 38 ESCOs are authorized in which 8 is for industry, 15 for building and 15 for both sectors. In the EE strategy, it is specified that these numbers shall be 50 up to 2015 but for only industrial sector activities. No other specification for building sector is stated.

In the last revision of En-Ver regulation, for being an ESCO, either A or B class certification could be possible for both residential and commercial buildings, defined as sub-categories under the building sector. If any ECSO wants to implement a project causing an increase in energy efficiency, the company should have A class certification, guaranteeing that it has ISO 9001 standard and an experience with regard to energy efficiency implementations.

Table 2. Incentives stated in current legislation and Energy Efficiency Strategy

Incentive	In En-Ver Regulation	In EE Strategy
Energy Efficiency (EE) Projects	. Defined for Industries with total energy consumption equal or greater than 1000 TOE (as an average of 3 years consumption) . According to sub- sector, scale of the project, target saving potential, the upper limit changes	. Reducing energy intensity and energy losses in both commercial buildings and industries. . Giving more attention to decrease in electricity usage as well as renewable energy projects.

Table 2. Incentives stated in current legislation and Energy Efficiency Strategy - continued

Incentive	In En-Ver Regulation	In EE Strategy
Voluntary Agreements	. Defined for Industries with total energy consumption equal or greater than 1000 TOE (as an average of 3 years consumption) . If you guarantee at least 10% energy saving in 3 years, the support of 20% of the energy cost in the starting year up to 200 000 TL (app. 80 000 EURO) as a grant	Reducing energy intensity and energy losses in both commercial buildings and industries. . Giving more attention to decrease in electricity usage as well as renewable energy projects.
ESCO activities	. For commercial buildings – with total construction area equal or greater than 20 000 m^2 / total energy consumption equal or greater than 500 TOE (as an average of 3 years consumption) For public/governmental buildings – with construction area equal or greater than 10 000 m^2 / total energy consumption equal or greater than 250 TOE (as an average of 3 years consumption) . Third party financing	.The cost of ESCO shall be included within the budget of EE projects that is incentivized.

Foreseen improvements in the current legislation

For the future, the main documentation that should be mentioned is Energy Efficiency Strategy (2012-2023). The main objective of this strategy is to decrease energy intensity of Turkey about 20% in 2023 as compared to 2011. Under this scope, a strategic aims, targets, and actions for energy efficiency in building sector and financing, defined in the strategy, can be summarized in Table 3.

Recommendations for sustainable ESCO market and financing

The following comments/recommendations are denoted not only for financial sector specialists but also for NGOs, public sector, academicians, private sector (producers, contractors), and energy managers, being also consumers in the society.

Common Terminology: The definition, classification and responsibilities of building sector (residential, commercial, public, service, tertiary) should be described clearly in order to well understand the related legislation and standards and to create a common terminology in line with the revised Energy Performance Directive (EPBD) in 2010 and related norms. Clearly described relevant terminology is very important for uniformly usage EU norms and development a sustainable market in buildings sector.

Table 3. Summary of future prospects of the Government on energy efficiency in building sector

Strategic Aims	Strategic Targets	Actions
Decrease in energy demand and carbon emission of buildings. Wide spreading of sustainable environmental friendly buildings with the utilization of renewable energy sources.	Among the buildings within the framework of "Urban Renovation Law" and Earthquake Regulation", commercial and service buildings with total usage area equal or greater than 10 000 m^2 should have heat insulation and efficient heating systems according to related standards in 2023.	On the basis of building function (hotel, shopping mall, hospital, etc.), climate conditions (temperature, wind effect, etc.), architectural design and current standards (TS 825, etc.), **maximum energy demand of the buildings** will be determined. Meeting maximum energy demand, energy efficient and/or clean energy resources will be evaluated primarily and related **maximum CO_2 emissions** will be calculated and if this limit is exceeded, **no permission will be given to construct a new building**. For the existing buildings, reducing CO_2 emissions to this maximum allowable value will be promoted and **after 2017, legal penalties will be applied**.
	Establishing sustainable building stock in 2023 i.e. renovating et least ¼ of 2010 stock in 2023.	Within 18 months after approval of the strategy, from commercial buildings, distinct luxury residential buildings and residences with total usable area equal or greater than 10 000 m^2**, a certificate, showing their sustainability as compared to international and national criteria** (poverty level of municipalities that the building is constructed, urban plans, value of construction areas and domestic energy resources) will be asked.
Strengthening institutional capacity, cooperation among governmental stakeholders. Increase in applications of advanced technologies and awareness. Developing financial mechanisms in addition to the governmental incentives.	Until the end of 2012, strengthening not only capacity of implementing institutions but also cooperation among them.	**Capacity building in the governmental and private institutions with regard to Building Energy Performance Regulation.** Capacity building in terms of **performance criteria, forecasting studies and integrated resource planning on energy efficiency and renewable energy areas for national and international benchmarking.**
	Studies considering establishment of carbon trading and market will be completed within 18 months after the approval of the strategy.	Developing **a road map/strategy for carbon trading/market formation** by workshops with the inclusion of all stakeholders.

Efficient/Intelligent/Green Building: EPBD suggests that all EU Member States endorse national plans and targets in order to promote the uptake of very low and close to zero energy buildings. These buildings should be efficient, “intelligent“ and “green”. Terms, concepts and calculation methodologies used for all types of low energy buildings vary significantly between EU Member States and beyond. Hence, as a target to reach, efficient/intelligent/green buildings or a combination of them should be defined clearly not only in nationwide but also internationally for the ease of benchmarking.

Indicators: Obligations together with incentives should be structured with true indicators corrected with climate and financial conditions. Indicators are quantitative and qualitative facts that are used to assess the progress of achieving a goal. Indicators must be relevant, credible, sufficient, independent and verifiable. They must also be clearly defined in terms of its nature, quality, quantity and timing. As the European countries are very different related to climate, financial, and other condition, these facts should be comprised by relevant indicators.

Targets for energy efficiency: For each class in the building sector, specific reduction targets for final energy intensity/energy consumption should be set in medium (2030) and long (2050) terms.

ISO 50001 Standard: In addition to energy manager obligation for commercial/public buildings, TS ISO 50001 and energy efficiency audits became mandatory, expressed in “Energy Efficiency Strategy (2011-2023)” in Turkey whereas it should be closely monitored.

Building Energy Performance: Within the framework of national regulations concerning building sector, especially for the existing buildings, total final energy consumption in specified unit (kWh/m^2/year), as well as specific energy consumptions of both passive and active systems (i.e. for lighting system kWh/m^2/year and W/m^2.100lx as performance and efficiency indicators, respectively), share of renewable energy sources in these values and also total greenhouse gas emissions should be calculated and verified accurately as main indicators.

Incentives: In current legislation in Turkey, there exist no direct incentives such as energy efficiency projects and voluntary agreements, designated to industrial sector, for building sector. Only in newly announced “Energy Efficiency Strategy (2011-2023)”, a provision is pointed out that the investments providing increase in energy efficiency shall be encouraged. However, this is surely not enough to extend existing and/or additional incentives for building sector. Hence, there should be a specific provision targeting to develop/explain attained incentives for buildings.

Credits: Concerning credit lines coming from international (EBRD, EU - Clean Investment Fund, World Bank, development/finance agencies of member states etc.), national donors (important banks in the finance sector) and also cooperation of them (TURSEFF – Turkey Sustainable Energy Facility, WEBSEFF, CEDEF, etc.), a guide book shall be prepared expressing which line could fit which project. SEFF programs were started at 2004. Total amount of budget is 1.3 billion Dollar and up to now, program are being applied in 14 countries. Together with 35 participant banks in these countries, over 700 million Dollar credit were utilized. TURSEFF was initiated in 2010 with 200 million Dollar funds. Table 4 presents the credit lines and the maximum allowable limits for that credits by TURSEFF [11].

Table 4. TURSEFF credit lines and corresponding maximum allowable limits

Credit Line	**Maximum allowable limit**
Energy Efficiency credits	§ Small sized: up to 300.000 US$ § Medium sized: >300.000-5 million US$
Renewable Energy credits	Up to 5 million US$
Energy Efficiency and Renewable Energy credits for **commercial buildings**	Up to 5 million US$
Energy Efficiency and Renewable Energy credits for **residential buildings**	Up to 75.000 US$
Supplier credits	Up to 1 million US$

In addition, there is an EU project entitled “Financing Energy Efficiency in Building Sector- EUBuild” aiming to contribute the development of the financial instruments and mechanisms in order to build up the market for energy efficient products and methods in the partner countries, Albania, Belgium, Bosnia-Herzegovina, Macedonia, Montenegro, Serbia and Turkey. Special objectives can be listed as follows [12]:

1. To create a database/document about energy efficiency regulations, incentives and financial mechanisms in the partner countries and in the EU and provide regular flow of information and knowledge sharing between project partners.

2. To provide coordination and regular flow of information between public institutions, private sector and NGO’s about developing financial instruments.

3. To develop recommendations for partner countries, European Commission and public institutions and make contributions for them to form strategic collaborations and action plans.

In terms of expected results the following outcomes could be stated:

1. A network shall be established among Turkish, Albanian, Macedonian, Serbian, Montenegrin, and Bosnian partners who have limited capacity in adopting energy efficient applications and implementing EU acquis and shared its expertise on the subject.

2. International conferences shall be organized and inter-country study visits of the representatives from partner organizations to share best practices: Improve the capacities of the sector as a whole on significance of adopting energy efficient applications and best-fit financial instruments.

3. As a result of awareness raising activities in line with increased knowledge about the new financial instruments and incentives there will be new products and methods in the market. It is expected with the availability of new tools and incentives end users production and consumption habits shall be changed in a positive manner.

Energy Performance Contracting: In general, obstacles for implementing performance contracting can be listed as: 1. existence of additional risk for the private partner, beyond the technical and economic risk of the project, due to deficiencies in legislation; 2. insufficient knowledge of the public sector (republic institutions, municipalities and users of the facility) about this manner of project financing; 3. insufficient capacity of budget beneficiaries for project financing, i.e. preparation of contracts, public procurement and monitoring the financial flows of such projects; 4. disparity of prices of fuels/energy; 5. cross subsidies for specific consumers; 6. lack of competent project developers and even 6. lack of domestic ESCOs. As a result, after having an ESCO market as a priority, EPC Scheme on the basis of national conditions, encouraging third party financing should be developed by all related stakeholders. For the standardization of EPCs, calculation/evaluation/monitoring tools like “International Performance Measurement and Verification Protocol-IPMVP” should be considered[12].

Demonstration Projects: Having huge energy potentials public buildings shall be evaluated to be good demonstration projects by the help of changes in Public Procurement Law to reflect a green procurement procedure.

Energy Saving Project Scale: Major problems related to the project identification and preparations are; problems related to ownership and users of the facility; related to the manner of financing operational costs including maintenance and the costs of future investment in retrofitting of the facility; related to the cost saving potential of the facility and related to the baseline assessment. To overcome these obstacles and to determine the frame of energy saving applications within the projects; small, medium, large scales energy efficiency and renewable energy projects should be identified together with their feasibilities as good demonstration projects or best practices.

Low Hanging Fruits: As a starting point for the energy efficiency project, “Low Hanging Fruits” should be evaluated. Targets or goals which are easily achievable and which do not require a lot of effort should be evaluated at the beginning on the every project. From this point of view, it is very useful that owners and tenants in old buildings be informed about simple measures for energy saving that give cheap and instantaneous results.

Monitoring and Inspection: For proper monitoring and inspection and management, especially for countries with very wide area like Turkey, an independent "Agency(ies)" should be established.

Database: Database formation has utmost importance for sharing best practices on financing energy efficiency projects. Establishing integrated information system (IMIS) between the Ministries and other Energy Agencies with the main goal to support sustainable development by enhancing information integration, data management and monitoring capacities in the energy sector shall be stated as one of the main outcome of this project and IMIS should provide efficient management, monitoring, reporting and information analysis resource for the use energy resources according to EU standards. Although EIE started a project considering such a database formation, the new structural change, mentioned above, results in postponing all projects of EIE.

Sustainability: Energy efficiency in building sector is not only the topic of energy but also economy, environment, land use practices/urban planning strategies (even earthquake management) to be regarded as a sustainable.

Environmentally efficient financial mechanism: Voluntary emission trading markets and if possible Clean Development Projects (CDM) should be improved in the favor of energy efficiency and renewable energy applications, two of which go hand by hand, in the building sector.

Towards Low Carbon Society: In the long run, sustainable energy/economy/environment/social efficiency means "low carbon society". Ministry of Energy and Natural Resources is planning to realize a project comprising the preparation of Turkish energy sector for international carbon market.

Consumer Responsibility: A network among all stakeholders, targeted by this project, should be developed for fruitful cooperation, remembering actually each of us is a consumer in any kinds of building.

Conclusion

As known by heart, ESCOs can be regarded as one of the crucial financing mechanisms for energy efficiency project implementations especially in the building sector. Unfortunately, up to now, in Turkey, mainly ESCO studies concentrate more on industry sector and no EPC application is realized. On the other hand, in order to have sustainable financing market for energy efficiency projects, in parallel with the best practices in international scale, more implementation projects should be carried out and public buildings can be a good option for demonstration. After changing Public Procurement Law, ESCOs shall have a chance to perform implementation projects in these buildings with high energy saving potential and a proper EPC scheme shall be developed for Turkey.

Recommendations, explained above, could be accepted as a strength-weakness-opportunity-threat (SWOT) analysis for sustainable finance market formation to promote energy efficiency in not only building sector but also industry. Keeping in mind that "every toe of energy you saved can result in a bulk of money in your pocket towards low carbon society", the discussion is already over and this is the time for not thinking but acting.

References

[1] EIE. General Directorate of Energy Sources Survey and Development Administration. *Energy Efficiency Strategy (2012-2023)*. (Ankara, 2011). Can be downloaded at: http://www.eie.gov.tr/duyurular/EV/EV-Strateji_Belgesi/Energy_Efficiency_Strategy_Paper_2012.pdf

[2] TEDAS, Turkish Electric Distribution Company, *Electricity Statistics 2009*, Can be downloaded at: http://www.tedas.gov.tr/29,Istatistiki_Bilgiler.html

[3] MENR. Ministry of Energy and Natural Resources. *Energy Balance in 2010*. Can be downloaded at: www.enerji.gov.tr/duyurular/2010_Yili_Genel_Enerji_Dengesi.pdf

[4] EIE.General Directorate of Energy Sources Survey and Development Administration. *Energy Efficiency Legislation and Implementations*. Energy Efficiency and Quality Symposium. Chambers of Electrical Engineers. (Kocaeli, 21-22 May 2009).

[5] Cornut B. *Key figures on buildings 2007*. Can be downloaded at: www.eie.gov.tr/turkce/en_tasarrufu/uetm/twinning/sunular/bina_11temmuz

[6] EIE. General Directorate of Energy Sources Survey and Development Administration. *Law on Energy Efficiency*. (Ankara, 2007). Can be downloaded at: www.eie.gov.tr/duyurular/EV/EV_kanunu/EnVerKanunu_Temmuz2008.pdf.

[7] MoPS. Ministry of Public Works and Settlement. *Regulation on Sharing the Expenses of Centralized Heating and Hot Water*. (Ankara, 2008). Can be downloaded at: www.mevzuat.adalet.gov.tr/html/27881.html.

[8] EIE. General Directorate of Energy Sources Survey and Development Administration. *Regulation on Efficient Utilization of Energy Sources and Energy*. (Ankara, 2008). Can be downloaded at: www.eie.gov.tr/duyurular/EV/EV_kanunu/EV_yonetmelik/EV_yonetmelik.html.

[9] MoP. Ministry of Public Works and Settlement. *Regulation on Building Energy Performance*, (Ankara, 2008). Can be downloaded at: www.binaisletimi.com/2008/12/binalarda-enerjiperformansi-yonetmeligi.

[10] MoEUP. Ministry of Energy and Urban Planning. *Energy Efficiency in Building Sector*. (Istanbul 2011). III. International Construction Quality Summit. (Istanbul, 23 November 2011).

[11] http://www.turseff.org/

[12] http://www.eubuild.com/eng/

[13] Marino A., Bertoldi P., Rezessy S., Boza-Kiss B. *Energy Service Companies Market in Europe, Status Report 2010*, Institute for Energy, JRC Scientific and Technical Reports. Can be downloaded at: http://publications.jrc.ec.europa.eu/repository/handle/111111111/15108.

Achieving Savings and Persistence – Practical Application of IPMVP in Commercial Buildings: Case Studies

David Jump, Ph.D., P.E.

Quantum Energy Services & Technologies, Inc.
Chair, Efficiency Valuation Organization IPMVP Committee

Tracy Phillips, CEM, LEED AP

7th Gen Energy Solutions
Member, Efficiency Valuation Organization IPMVP Committee

Abstract

This paper presents three case studies about the practical application of IPMVP's measurement and verification (M&V) methods in commercial building projects. They demonstrate use of IPMVP's options in verifying savings:

- Two case studies (a 23,500 m^2 commercial office building and a 10,100 m^2 university computer science building) concern existing building commissioning (EBCx) projects, where savings are difficult to quantify. IPMVP's Option B and C were employed in these cases.

- Another EBCx project case study utilized calibrated simulations of a large office building with measures improving its air distribution, chilled and hot water system operations; Option D was used.

M&V was applied to address stated project goals including increasing confidence in savings and energy performance, and meeting green building certification goals. How data was identified, collected, and analyzed is presented. The costs of applying M&V to these projects are described.

The studies highlight how M&V added significant benefits for incremental project costs. Benefits include: providing tools to maintain and improve energy performance, accurate savings accounting, obtaining green building certification credits, and improving energy efficiency program reporting and third party review processes.

This work led to development of guidelines that provide detailed technical information on implementing M&V in adherence with IPMVP's methods. A summary of EVO's role in maintaining standards in M&V, providing technical training, and fostering new developments in the field to implement M&V more cost-effectively is described.

Introduction

General procedures for measurement and verification (M&V) of energy savings resulting from energy conservation projects and programs and best practices in applying them have long been established [1]. The Efficiency Valuation Organization (EVO) provides and maintains the International Measurement and Verification Protocol (IPMVP) [2], which provides a flexible framework of options in applying M&V. The IPMVP has been translated in multiple languages and is used in over 40 different countries. While IPMVP provides parties involved in energy conservation projects guidance on procedures to assure a specific project delivers the expected savings, IPMVP-adherent M&V is not yet a widespread practice throughout the world. This is due to several reasons:

1. IPMVP describes principles of M&V and four options that may be employed, but requires the parties involved to define the specific steps used to ultimately verify improved energy performance and quantify the savings. This requires M&V expertise for all parties involved in a transaction. Often parties involved do not share the same level of knowledge.

2. M&V is often thought of as an activity coming at the end of a project when in reality it requires actions before and after energy conservation measures (ECMs) are installed

3. M&V is perceived as too costly and requiring specialized skills and resources beyond those needed in the project.

In this paper, we present practical application of IPMVP's methods in the form of three case studies. These case studies are in commercial buildings, and demonstrate methods of applying M&V, including identifying and preparing data, developing baseline energy models, and quantifying savings. The value M&V provides beyond quantifying a project's savings is discussed, including increasing confidence in savings realization, extending persistence of savings, and obtaining credits under green building certification programs.

Measurement and Verification

As described in IPMVP, two fundamental M&V criteria are: 1) savings are based on the difference between baseline and post-installation energy use, with either baseline or both baseline and post-installation energy use adjusted to a common set of conditions, and 2) the improved performance of systems, due to the installed energy conservation measures (ECMs), must be verified to demonstrate that they will generate the expected savings.

To meet the first criteria, energy models are developed, which can be empirical models, such as statistical regressions, or physical models as found in building simulation software, that describe the energy usage of all the equipment inside the measurement boundary. Measurement boundaries may be drawn around the whole building, or specific building subsystems. IPMVP's Option A and B are retrofit isolation methods that verify savings in specific building subsystems. IPMVP's Option C is a whole-building method employing empirical models. IPMVP's Option D is a calibrated simulation method that can be applied to whole buildings or to building subsystems.

To meet the second criteria, the operational performance of the improved systems and equipment are verified against expected performance. For example, the improved efficiency of a newly installed chiller is verified using measurements of chilled water temperatures, flow, and chiller power, or an occupancy sensor is verified to shut off area lighting when there is no movement in the room. This 'operational verification' may be applied with increasing levels of rigor, as required by each installed ECM. Operational verification provides assurance that the resulting savings is due to the properly installed and operating ECMs.

Case Studies

Three case studies are presented to demonstrate how different M&V options are applied to verify savings. Each case study involves an existing building commissioning project, where energy savings are obtained from improving the operations of existing mechanical and electrical systems within the building, as opposed to installing more capital intensive ECMs, such as replacing inefficient chillers, boilers, or lighting systems. EBCx overlaps with M&V as both activities require that the operational performance of the improved building systems be verified. This is often accomplished with the collection and analysis of monitored operational data (specifically temperatures, pressures, air and water flows within the system, and so on). One case study will show how this collected data was used to calibrate a baseline simulation model for the building.

In the first two case studies, M&V is used to show the actual savings resulting from the EBCx projects. The third case study is about use of calibrated simulation-based M&V to help achieve green building certification credits [3]. We describe the buildings, their systems, the savings measures, and how M&V was applied for each project.

Case Study #1 Office Building in Oakland California

An EBCx project was conducted in a large (23,500 m^2) office building in Oakland California. The building has eight floors on top of a four floor parking garage. It was built in 1998 with masonry and steel construction. Space cooling is provided with two 250-ton water-cooled chillers providing chilled water in a constant volume, primary-only system to coils in two large built-up variable-speed air handler units. A two-cell, open loop, draw-through cooling tower provides condenser water to the chillers. Two variable-air-volume built-up air handlers circulate air to the building's eight occupied floors, eventually to fan-powered terminal boxes that serve individual zones. Air is returned through ceiling plenums to the central air shaft. Six variable speed exhaust fans remove a portion of the return air and fresh air is supplied through economizer dampers. Two 1,600 MBTUH boilers provide hot water to six fan-coil units on each occupied floor. Second generation (T-8) florescent lighting with electronic ballasts illuminate each floor and are controlled by a separate lighting control system.

The building's electric meter provided readings of kWh consumption every 15 minutes; this data was available from the local utility. The building's natural gas consumption was provided from monthly utility bills.

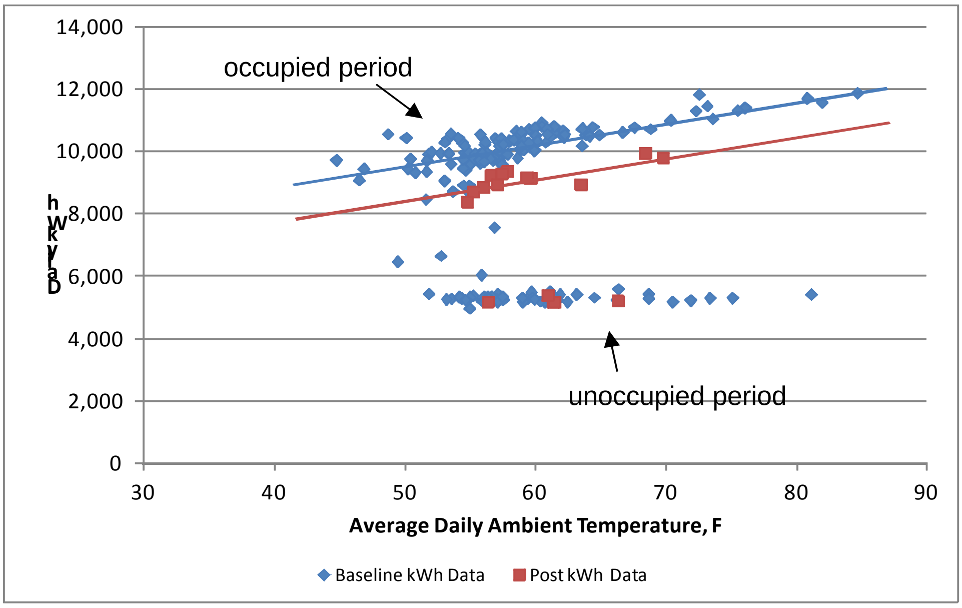
The EBCx project generated an extensive list of problems in the operational performance of the heating, ventilating, and air-conditioning (HVAC) and lighting systems. Correcting these problems lead to significant energy savings. Table 1 provides the list of measures that were implemented. These issues were corrected as part of the EBCx project.

Table 1. Office building operational deficiencies.

System	Issue Description
AHU1 & AHU2	Excessive operation schedule: the fans are started too early each day.
	Faulty economizer operation: actuators are not opening or closing the economizer dampers fully
	Constant speed operation: the fans are not modulating their speed, are running at 100% speed constantly
High electric load at night	Fan-coil unit and VAV terminal box fans running at night
	Lighting on several floors are not shutting off at night

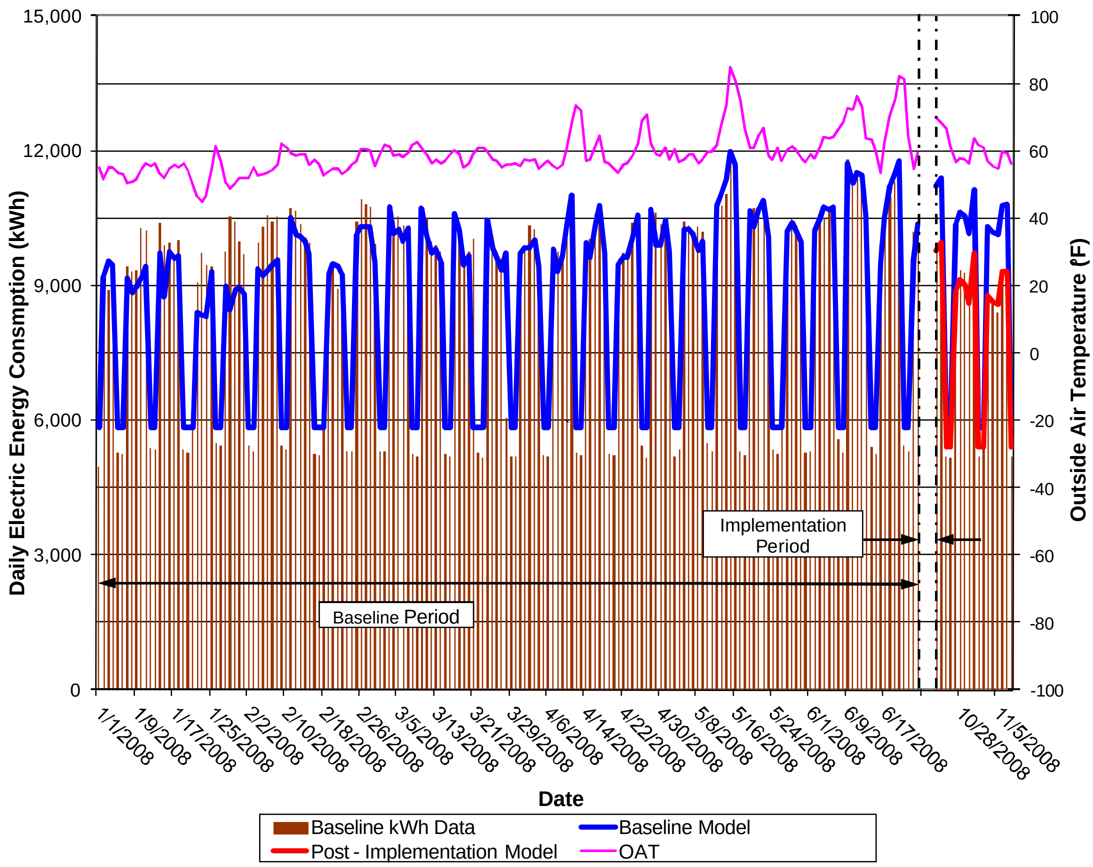
The M&V strategy employed for this project was Option C: Whole Building, using regressions for the baseline energy models. We collected six months of whole-building 15-minute interval electric energy data from the local utility, as well as ambient temperature data from a local weather station. Electric energy data was summed to daily totals and ambient temperature was averaged over the day. Weekdays were separated from weekends and holidays and separate models were made for these distinct operating periods. The data and resulting baseline and post-installation energy models are shown in Figure 1.

Figure 1. Scatter plot showing baseline and post-installation energy models (occupied period)



For this project, the data showed significant savings resulting from addressing the problems identified in the table. Savings are demonstrated in Figure 2 on the right hand side of the chart where the measured whole-building daily energy use is less than the forecasted baseline regression model. Since this was a partial list of the identified measures, the owners decided to implement additional measures over time, and verify that savings were continuing to accrue. A post-installation model was developed in order to track performance of the implemented measures of Table 1.

Figure 2. Time-series plot showing forecast of baseline model in post-installation period.



Case Study #2: University Computer Science Building

An EBCx project was conducted in a 10,100 m^2 university computer science building in Berkeley, California. Prior to conducting this project, electric and steam metering was installed to measure whole-building energy consumption in short time intervals. The building has seven floors above grade, and two below grade. It provides computer laboratories and classrooms, several data server rooms, an auditorium, and faculty and staff offices. For space cooling, it has two 125-ton chillers, and two dual-speed cooling towers. It has a primary-secondary chilled water system serving three variable air volume (VAV) air handler units (AHU). One AHU serves the interior zones and has a cooling and heating coil. The other two AHU serve the east and west side perimeter zones. The perimeter zone VAV boxes have hot water reheat coils. Hot water from a heat exchanger using campus steam is circulated to the heating coils in the perimeter zones as well as the main interior zone AHU. A building automation system monitors and controls all equipment in the central plant and air distribution system and maintains required space temperatures. The university archives six months of change-of-value data of all monitored points at one minute intervals, providing a rich data set for analysis and M&V.

This EBCx project was focused on improving the performance of the building's HVAC systems. Several defective equipment components were identified, as well as inefficient system operational strategies. Table 2 provides a list of the recommended improvements to HVAC operations for this building, as well as their estimated energy savings. Savings were estimated using whole building simulation software (eQUEST).

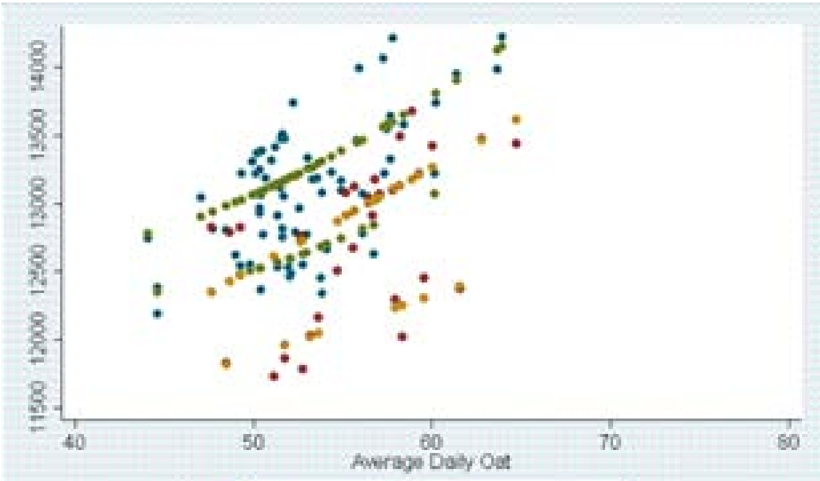
Table 2. Recommended improvements, costs and benefits

			Estimated Savings				
Measure No.	**Description**	**Implementation Date**	**Energy, kWh/yr**	**Energy, lbs/yr**	**Dollars, $/yr**	**Estimated Measure Cost, $**	**Payback, yr**
AHU1-2	Resume supply air temperature reset control and return economizer to normal operation	10/25/2006	129,800	266,250	$19,004	$1,550	0.1
AHU1-3	Repair/replace VFDs in return fans	10/25/2006	34,308		$4,460	$7,000	1.6
AHU1-4	Reduce high minimum VAV box damper position	3/9/2006	46,300	119,300	$6,973	$15,250	2.2
AHU3-2 & AHU4-2	Option 2: Reduce high minimum VAV box damper position	3/9/2006	30,600	2,328,100	$22,603	$17,250	0.8
AHU3-3 & AHU4-3	Re-establish scheduled fan operation and VAV AHU-3 (includes repair/replace VFD on return fan EF-17), AHU-4 (includes repair/replace VFDs on supply SF-18 and return EF-19 fans, and elimination of low VFD speed setting during the day)	10/25/2006	242,000		$31,460	$14,000	0.4
Total			**483,008**	**2,713,650**	**$84,500**	**$55,050**	0.7
		Percentage Savings	10%	51%	14%		
		Utility Data	Steam	5,325,717	lbs		
			Electricity	4,871,678	kWhr		
			Cost	$621,575			

These savings opportunities were found primarily in the air distribution system. Savings were expected from reduced fan operation, as well as reduced chilled water and hot water use. The savings measures included simple control system programming changes, repair or replacement of malfunctioning variable-speed drive equipment, and manual reduction of air flows to individual zones through adjustment of terminal box minimum damper settings. While some of these measures incurred a significant initial cost, the overall payback for the set of measures (excluding fees and metering costs) was still less than one year, due to the high amount of savings expected.

An Option C whole-building method was employed. The five-minute interval energy data was summed to daily totals of energy use, and paired with average daily ambient temperatures for six months of baseline period data. Figure 3 shows the scatter plot of both baseline and post-installation energy use versus temperature. It also shows the linear regression models developed from the data. This chart shows a high degree of scatter in the data, so much so that the expected savings is obscured.

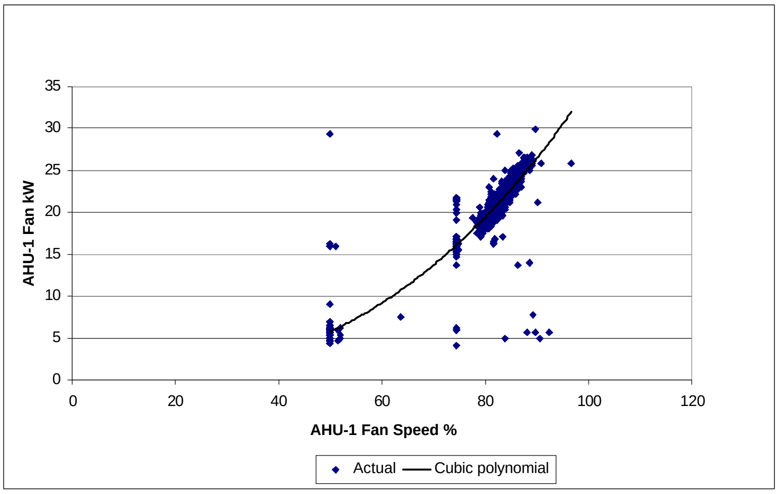
Figure 3. Whole-building baseline and post-installation energy use.



Because of the rich data set available, an Option B retrofit isolation approach was also employed. In this case, the entire HVAC system was isolated and all energy flows into it were identified. This included all fans, pumps, chillers and cooling towers in the building. To quantify the energy use of each individual component within the measurement boundary, their energy use characteristics were identified as constant or variable. For constant load equipment, a simple spot measurement of power was made as the equipment was operating. Constant load equipment included constant speed primary pumps, and supply and return fans with malfunctioning variable frequency drives (VFDs). The two-speed cooling towers were also treated as constant load equipment. Archived feedback status signal data for the constant load equipment, which were recorded as “0” for “off” and “1” for “on,” were multiplied by the measured power. The total energy use of the constant load equipment each day was then determined.

For variable load equipment, independent data loggers were used to determine the power as the equipment ranged through its range of operation. Variable load equipment included operable VFD-controlled supply and return fans, and VFD-driven pump motors. Simultaneously monitored variable load signals, such as pump or fan speed, were used to determine their relationship with measured power as the equipment varied through its ranges of loads. An example of a fan speed signal converted into a “proxy” variable for power is shown in Figure 4.

Figure 4. Fans speed signal used as a proxy for power.



Daily HVAC system energy use was determined from the daily totals of all constant and variable load equipment inside the measurement boundary (chiller power was already a point monitored and archived with the other control system data). Figure 5 shows the scatter plot of HVAC energy use and average daily ambient temperature. In this case, the data show much less variation around the model, which increases confidence in the savings estimates. Figure 6 shows the same information in a time-series plot.

Figure 5. HVAC energy use

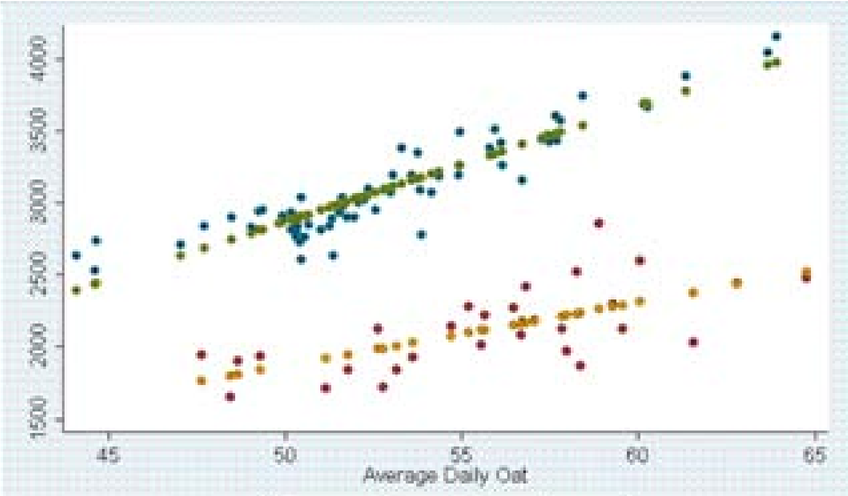
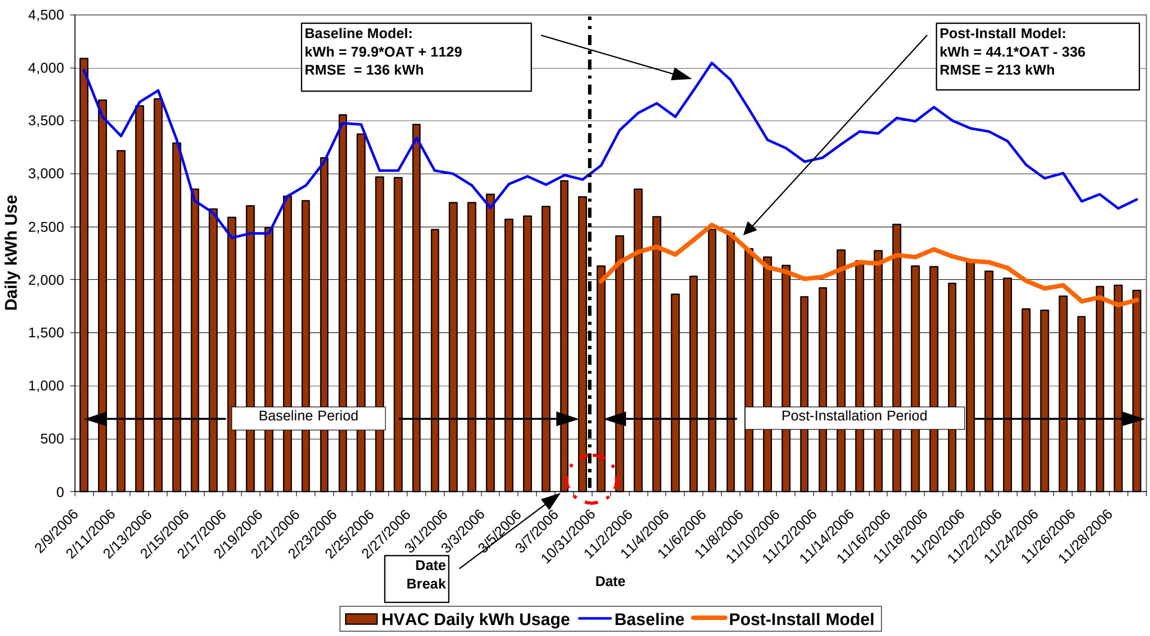


Figure 6. Forecast of baseline energy use into post-installation period, demonstrating realized savings.



Verified savings are shown in Table 3. Due to the better fit of the baseline and post-installation models to the data, there is more confidence in the Option B HVAC system approach as opposed to the whole-building approach as shown in Figure 3.

Table 3. Estimated vs. Verified Savings.

Source	Estimated Savings*	Verified Savings**	
		Whole Building	HVAC System
kWh	483,008	216,716	462,472
kW	-	22	50
Lbs. Steam	2,713,650	854,407	

* based on eQUEST model

** based on baseline and post-installation measurements and TMY OAT data

Due to the rich data set available, the six months of archived data, and the high level of savings compared to project costs, the additional costs due to M&V did not ruin the project's cost-effectiveness. For this project, the overall costs and simple payback are shown in Table 4.

Table 4. Computer Science Building Project Costs

Metering Costs	Fee	In-House Costs	Total	Total Savings	Payback
$ 13,508	$ 62,160	$ 51,087	$ 126,755	$ 69,229	1.8

Case Study #3. GSA Building in Lakewood Colorado

For a green building certification project [3], an EBCx project was conducted in an office building in Lakewood Colorado using an IPMVP Option D Calibrated Simulation method. This building is a three-story 12,000 m^2 office building with a 10,500 m^2 garage. Its HVAC systems included one VAV AHU system and two VAV roof-top unit (RTU) HVAC systems. Each unit has hot water and chilled water coils, and their terminal boxes had hot water reheat coils. Two water cooled centrifugal chillers provided chilled water through a primary-secondary chilled water system. Two gas-fired boiled provide hot water, also through a primary-secondary system.

In this project, the green building certification required that an EBCx plan be developed and carried out, that any flaws in system energy performance be corrected, that new operational strategies customized for the building's current requirements be implemented, and that proper building documentation and staff training be provided in order to maintain optimized performance over time. Each of these items would generate credits toward certification. Additional credits were available for development and implementation of an M&V plan adherent with IPMVP.

In this project, data from the control system and from independently installed temporary data loggers were used extensively to detect and identify operational performance flaws. Monthly energy data was available from the local utility for recent past years. Because of the amount of data made available through the EBCx portion of the project, an IPMVP Option D Calibrated Simulation method was used to obtain M&V credits. The measured data on system operational parameters, including HVAC and lighting systems was used to calibrate the simulation model. The overall model was tuned to the monthly utility bills. The resulting calibrated model was used as the baseline model, and the savings from correcting the individual performance deficiencies were determined from this baseline simulation model.

Performance tests conducted for this building included:

- HVAC equipment schedules, including optimum start / stop operation
- VAV operation on AHUs and roof top units
- Supply air temperature reset based on zone heating / cooling needs
- Demand controlled ventilation
- Airside economizing
- Cooling Tower VFD operation

- Chiller scheduling, disabled below 50F ambient temperature
- Hot water and Chilled water variable-flow operation
- Hot water reset, based on ambient temperature
- Boiler efficiencies (combustion analysis test)

Performance deficiencies identified for this building included premature closing of economizer dampers, too-early start-up of HVAC systems, and continuous chiller operation, as demonstrated in Figures 7a, 7b, and 7c below.

Figure 7a. Economizer damper performance.

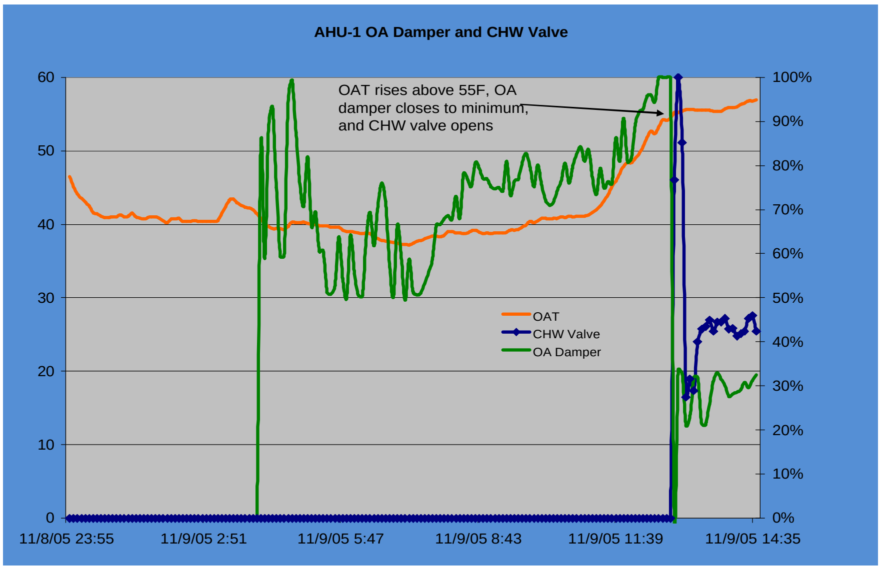


Figure 7b. HVAC scheduling.

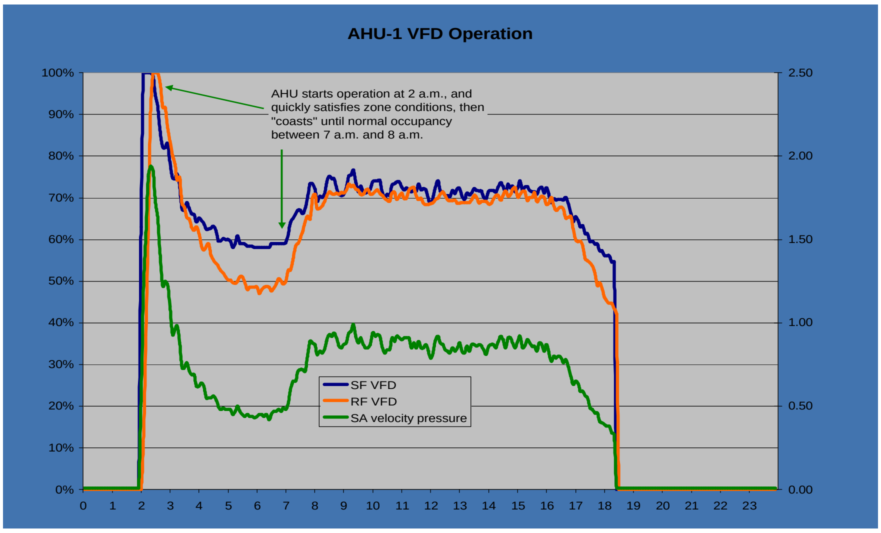
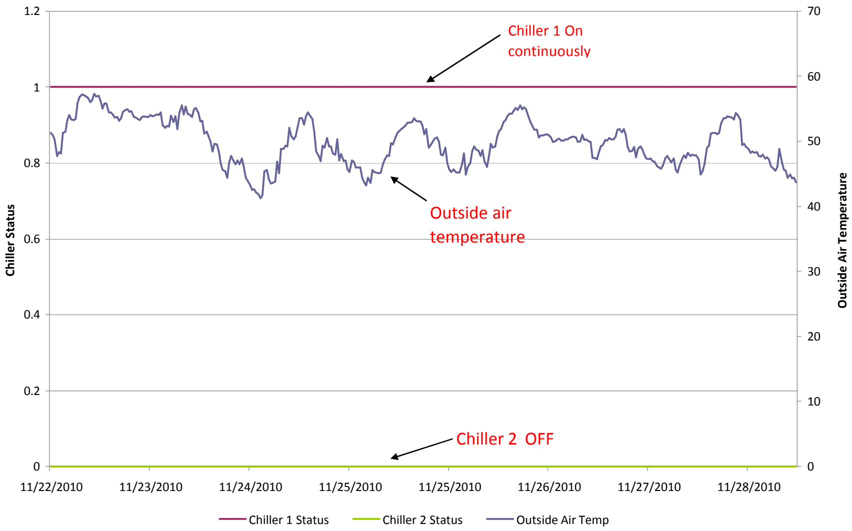


Figure 7c. Chiller operation.



This operational data, normally collected to identify flaws in system operations, was used to calibrate the building simulation model. This level of detail in calibrating building subsystems assured that not only was the overall simulation tuned to the monthly bills, but that the proportion of end-uses (e.g. heating, cooling, ventilation, lighting, and plug loads) within the building were also correct. As these operational flaws were implemented, the diagnostic tests were repeated to assure the new systems were operating as expected. After all the measures were installed, measured post-installation whole building energy use was subtracted from the baseline model's estimate of energy use to obtain the savings.

Summary of Added Benefits

In all three case studies, application of M&V methods served to increase confidence in a project's reported savings. This is particularly true for EBCx projects where estimates of savings from engineering calculations can be uncertain due to the high degree of interaction among systems and that rely on multiple assumptions that may prove invalid. In cases where ECMs are installed throughout the building (case studies 1 and 3), whole-building methods (Option C or D) are appropriate to account for savings, provided that each improved system's operational performance is verified. Where savings are concentrated in a building subsystem (case study 2), a retrofit isolation approach (Option B) is appropriate.

Case study 2 demonstrated that the same regression-based methodology may be applied to any measurement boundary, as long as both the dependent (energy) and independent (ambient temperature) variables may be monitored for the appropriate amount of time. The number of data points and sources for whole-building methods include the local utility and a local weather station in most cases. This reduces the amount of time needed to collect and prepare the data. As was demonstrated in case study #2, when measurement boundaries are drawn around building subsystems, each system component's energy use over the monitoring period must be collected and there are as many data points as there are components. Because each component's energy use is not typically monitored and archived, some work is required to develop "proxy" energy variables, and to continuously monitor them. Option B using the regression approach requires more labor in general than Option C. The benefit of employing Option B is much improved confidence in a project's resulting savings, see also [4]. It should be noted that advances in monitoring and analytic technology will reduce this method's costs.

Each case study shows that building energy models, whether regression or simulation based, has value beyond quantifying savings. A characteristic of many types of EBCx project ECMs is that they can be defeated too easily. Examples include changes to control system settings, such as temperature or pressure set points and HVAC system operation schedules. Often, to address a local occupant discomfort complaint in a building, the global zone set point will be adjusted back to setting prior to the EBCx project. This reduces the savings by degrading the building energy performance. A building energy model developed from post-installation period data can be used to maintain energy performance over time by comparing expected performance with actual performance, and finding and correcting flaws in system operations that cause the performance degradation.

New Guidelines, Tools, & EVO's Role

The use of statistical regressions in M&V has traditionally been understood as an application under Option C Whole Building. Case studies 1 and 2 demonstrate its use with measured short time interval data and in applying it to building subsystems. Use of short time interval data has additional benefits. It provides more information on building or subsystem energy use in a shorter time that is very helpful in understanding how systems are performing. Baseline and post-installation energy models may be developed more rapidly as opposed to whole-building models using monthly data.

Recognizing this potential, the California Commissioning Collaborative (CCC) [5] sponsored the development of new guidelines for developing energy models based on measured short time interval energy and independent variable data to implement M&V methods as part of EBCx projects [6]. The CCC is working with EVO to accept these guidelines as part of EVO's family of documents that provide good guidance and best practices to applying IPMVP-adherent M&V in actual situations. In this way, EVO carries out its mission to promote confidence in the returns on investments among parties involved in energy savings projects.

Finally, the regression approach for defining baseline models may be programmed as a tool. Baseline models are not simple linear regressions with one parameter. They may be change-point models [7], multiple regression models, or more complex models [8]. The California Energy Commission is currently funding a project to provide regression and M&V analysis in a free, easy to use tool.

References

[1] Haberl, J. S. and Culp, C. H., *Review of Methods for Measuring and Verifying Savings from Energy Conservation Retrofits to Existing Buildings*, Energy Systems Laboratory, Texas A&M University, ESL TR-03/09-01, September 2003.

[2] EVO (2012). *International Performance Measurement and Verification Protocol (IPMVP).* Efficiency Valuation Organization www.evo-world.org.

[3] Leadership in Energy and Environmental Design (LEED). US Green Building Council, www.usgbc.org

[4] Jump, D., M. Denny, J. Gallishaw, D. Wiedwald. "After the (RCx) Party is Over – Unrequited or Life Long Savings?," proc. National Conference on Building Commissioning, Chicago, Il, April 22-24, 2008

[5] California Commissioning Collaborative, www.cacx.org

[6] Jump, D. and Gillespie, K., *Guidelines for Verifying Existing Building Commissioning Project Savings - Using Interval Data Energy Models: IPMVP Options B and C*, November 2008, California Commissioning Collaborative, www.cacx.org.

[7] Development of a Toolkit for Calculating Linear, Change–Point Linear and Multiple–Linear Inverse Building Energy Analysis Models", Research Project 1050, American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE).

[8] Quantifying Changes in Building Energy Use, With Application to Demand Response, J.L. Mathieu, P.N. Price, S. Kilccote, and M.A. Piette, Lawrence Berkeley National Laboratory, report no. 4944E. http://drrc.lbl.gov/system/files/LBNL-4944E.pdf.

The Best Energy Project – Information and Communication Technologies for the Improvement of Energy Efficient Building Operation and User Involvement

M.Sc. Hanna Soldaty, Dipl.-Ing. Architect Stefan Plesser, Univ.-Prof.Dr.-Ing. M.Norbert Fisch

Institute of Building Services and Energy Design, Technische Universität Braunschweig

Abstract

This paper has been elaborated in a research project carried out by the IGS - Institute for Building Services and Energy Design at the Technical University of Braunschweig. The Best Energy Project (European Commission ICT PSP) is to verify opportunities of reduction in energy consumption in public buildings and street lighting by practical application of information and communication technologies (ICT).

In the frame of the project several measures for improvement, both technical and related to users' behaviour, were defined and are being implemented by IGS at one of the university's building in Braunschweig. The initially quantified objective was to achieve 12% reduction in the energy consumption of the buildings.

The paper discusses:

- The implementation of the ICT and optimization measures
- Experiences from the project
- The results and achieved savings in electrical and heating energy.

Best Energy – Built Environment Sustainability and Technology in Energy

The goal of the project was to implement ICT-based centralized monitoring and management of the energy consumption and production in public buildings and street lighting to provide decision makers with necessary tools enabling identification and implementation of the energy saving measures. The monitored operation parameters and energy consumption constitute the basis for the analysis of the systems operation and optimization process. Moreover the feedback about the building performance given to users, maintenance staff and the public increases the awareness of the energy consumption and thus stimulates the positive changes in everyday behaviours to increase energy savings.

IGS plays an important role in the Best Energy team by implementing and validating one of two building pilots at the Technical University of Braunschweig, Germany, and by supporting the replication process in the New City Hall in Viborg, Denmark. One of the implemented tools is the internet based platform *energie navigator*, developed by synavision GmbH, which allows the precise specification and verification of the building operation, function of particular systems and energy consumption.

Second feature of the tool is the integration and motivation of users directly and indirectly influencing the energy consumption in the building, like for example office staff, visitors, technicians or building management. An online platform gives them an opportunity to have a general overview on the energy consumption in the building as well as to check the estimated energy consumption, CO_2 emissions and costs for energy in the current year in comparison to the benchmark year. Moreover, the decision makers receive information on the building operation and support for design and realization of optimization measures.

Pilot project: Centre of Informatics of Technical University of Braunschweig

One of the pilot projects is the Centre of Informatics - a complex of two buildings located on the campus of Technical University of Braunschweig. It is a typical university building for teaching and research with offices, lecture rooms, workshops and work stands for students. The multi-storey building was built in 1976 and was extended by a new part in 2001. The building is used by the faculties of architecture and informatics - the old part belongs to institutes of architecture, and the new one to informatics.

Figure 1 Centre of Informatics of Technical University of Braunschweig

The new part was designed and realized with an innovative energy concept for heating and natural ventilation as a state of the art demo building in the EnOB research programme for energy-optimized construction funded by the Federal Ministry of Economics and Technology. All six floors of the old part, connected to the new part, were also refurbished in the course of the construction. The 9th floor was retrofitted in 2010. The innovative concept was realised as *future workspace* pilot project funded by the Federal Ministry of Economics and Technology. The two upper floors, where the students' stands are located, will be renovated with the concept based on best practice in energy efficient solutions. The expected time of refurbishment is 2012.

The building is supplied with energy from the electrical grid and from district heating. The cooling energy is produced by two compression chillers and used only for servers cooling purposes. The waste heat from chillers is used for preheating of the atrium. The offices and lecture rooms are ventilated naturally through windows.

The building is characterized by an already low heating energy consumption (68 kWh/m^2) in comparison with reference value from German standard EnEV 2009 for heating in office building, which is 105 kWh/m^2 whereas the electrical energy consumption (60 kWh/m^2) is twice higher than the corresponding reference value. [1]

Technical optimization in the building

The set of optimization measures was established due to the preliminary analysis based on a breakdown of the energy consumption data, an audit of the building and web questionnaires handed out to the office staff and building management.

The preliminary analysis was a basis for a balance of the electrical energy consumed in the building. According to the presented results the further optimization measures were defined.

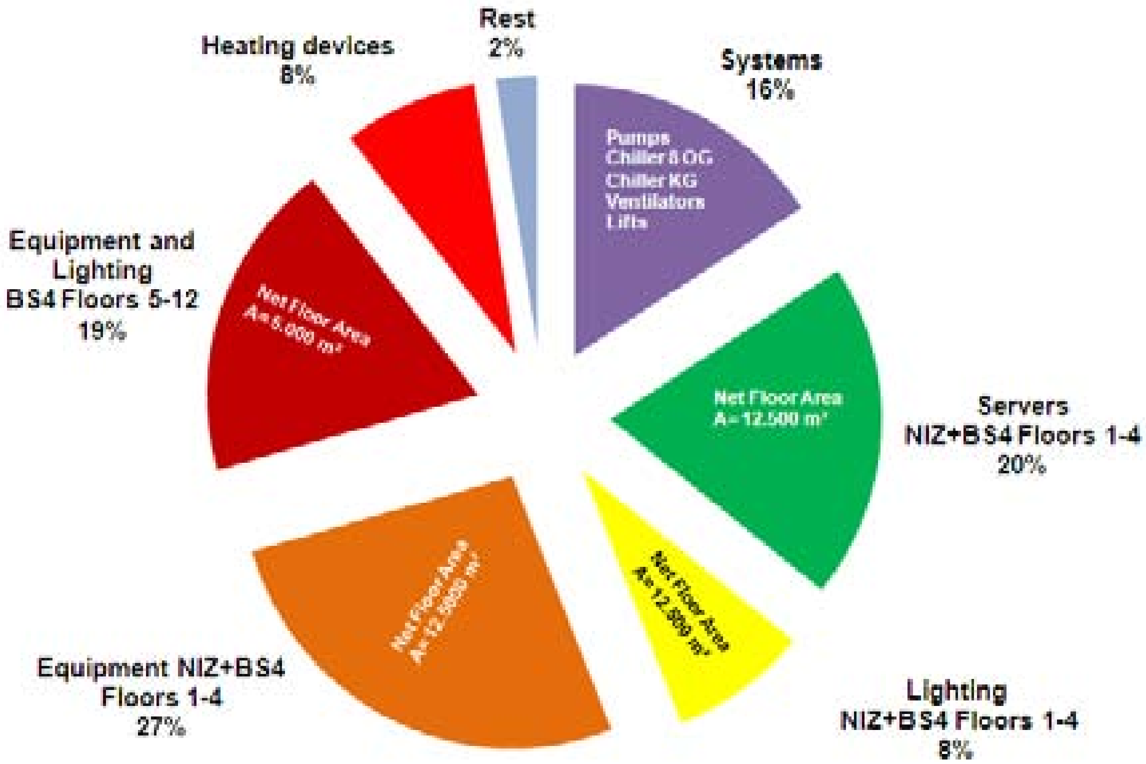


Figure 2 Electrical energy consumption in the Centre of Informatics of Technical University of Braunschweig

Due to the analysis the highest electrical energy consumption in the building is related to office equipment, lighting and server rooms.

The building is equipped with different kind of lighting regulated either completely manually or both manually and automatically. In the new part and renovated floors in the old part the direct-indirect lighting system is installed. The lamps are regulated by day light (lux level) and motion sensors. The lighting and shading systems in the new part are connected to LONBus and can also be individually regulated by users (for example position of the shading devices). The floors in the old part of the building are equipped with a different kind of lighting, mostly obsolete and less energy efficient. The recommended replacement of the old lighting system is only profitable by the total overhaul of the floors, which is planned floor by floor.

The analysis of the electrical energy consumption of the office equipment showed that the elimination of stand-by and the replacement of the old, inefficient electrical equipment have potentials for energy efficiency improvement. The high performance computers installed in the offices and in the CAD-pools for students required high power demand and run 24 hours per day, which is unavoidable. However the other typical office equipment like computers, monitors, laptops, portable hard discs, copy machines, faxes or coffee machines also stays in stand-by modus during the nights, weekends and holiday breaks. The replacement of the old equipment with more efficient devices would reduce energy consumption significantly; the challenge here is less technical but to improve the procurement procedures for electronic equipment.

Also the server rooms have a high potential of improvement, especially the spatial structure and layout of the room. The volume of most of the server rooms showed to be inadequate for the purpose notably influencing the energy consumption. The most crucial issue is server cooling – the incorrect placement of the chillers and the air volume rate in the room to be additionally cooled down - affect efficiency of cooling and thus the energy consumption. Beyond the replacement of the computers used as servers would have a positive influence on the energy consumption and is highly recommended. One obstacle for the implementation of the measures is decentralized data storage at each institute. The reorganization of the server room is time- and money-consuming, but a key objective of the university.

According to interviews with office staff, site inspections and analysis of data from the building management system in the building done by the Best Energy team, the installed heating system is insufficient to meet the required temperature level in the new part of the building although sufficient heat is being supplied to the building. To assure the temperature comfort the additional electrical heating devices are in use during the heating period. Corresponding to the survey on users comfort carried out by environmental psychologists from Saarland University, more than a half of the respondents was unsatisfied with thermal comfort in the building and perceives that fact as highly influencing their well-being at work. The inspection of the heating system revealed an unbalanced distribution of heat in the building. As cause a corrosion of the pipes and clogging up of the valves with magnetite particles was identified. The recommended exchange of the valves is about to bring not only improvement in heating system and thus the optimization of the heating energy consumption by ensuring users comfort, but also a reduction in electrical energy consumption by eliminating the inefficient electrical heating devices. [2]

Users´ involvement

Not only technical enhancement process in the building operation, but also the behaviour aspect played a key role in the optimization plan. Parallel to technical improvements, also measures to increase user awareness and motivate to enhanced behaviours have been implemented in the Centre for Informatics. The office staff, students and building management were involved in the optimization process through information campaigns and direct cooperation. Through newsletters, flyers and posters all interested parties received information on the planed and realized measures as well as hints for energy savings. The workshops and surveys facilitate an exchange of the ideas and discussion. Moreover users and public have a possibility to view the buildings energy consumption on a special website. Apart from the energy consumption also potential savings in energy (kWh/a), CO_2 (ton CO_2/a) and costs (€/a) are presented in comparison to the benchmark year [3].

Figure 3 Energie-Navigator website

To verify the effectiveness of the motivation campaign the evaluation of the energy consumption in the building before and after the measure was done. One of the newsletters was sent as a reminder to turn off the electrical devices to avoid leaving them in stand-by modus during weekends. The comparison to preceding and following weekends as well as to the adequate weekend one year before showed the explicit decrease in a base load. However the effect was temporary and the base load returned to the initial level after a few days, which proves that the challenge is a constant motivation of the office staff to turn off stand-by.

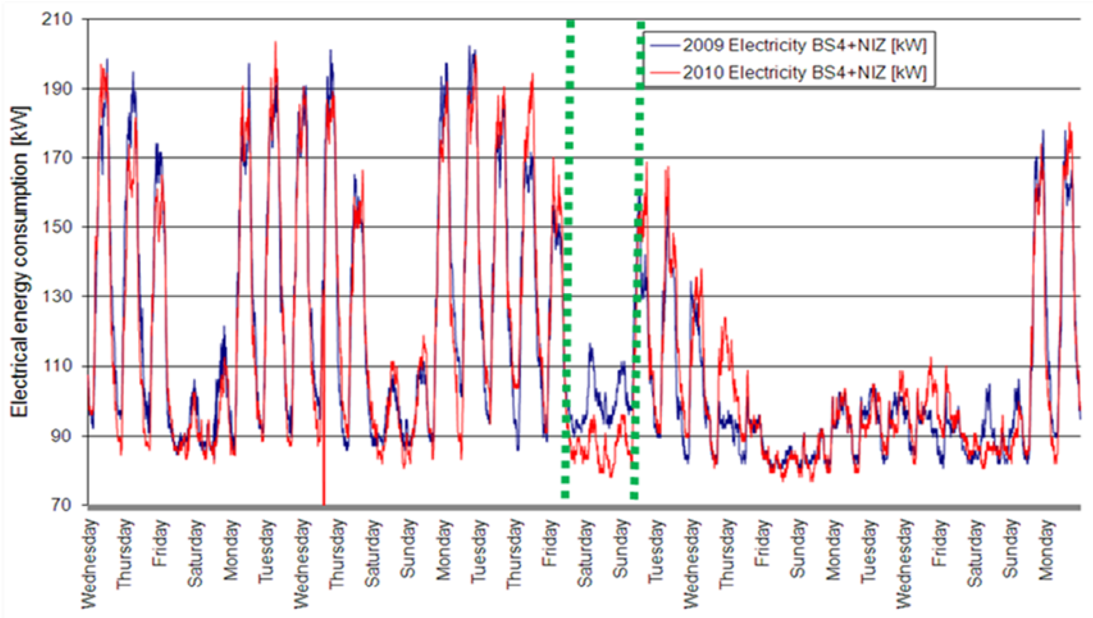


Figure 4 Energy consumption in comparision to the weekend preceding and following the reminder and in the adequate time one year before

To evaluate the influence of the detailed monitoring the giant screen with information about the electrical and heating energy consumption as well as conditions in the offices (like temperature, CO_2 concentration and light density) was installed in the hall of the 9th floor.

Figure 5 The giant screen installed on the 9th floor of the building

The information displayed on the screen aroused not only curiosity of the employees working in the offices, but also visitors and students attending the lectures in the institute.

During the last phase of the project, the research team installed an additional monitoring-control system in a number of offices in the building. The installed system called Plugwise consists of 50 switches to be plugged between the sockets and appliances measuring the energy consumption and apply the on/off-schedules. The data are transmitted and collected in the computer which enables users to have an overview and control of the energy consumption of the plugged devices.

Figure 6 Printer pluged with the PlugWise

The additional merit is possibility to program the adequate schedules for the particular devices to turn them off during the night and weekends as well as to turn off automatically the devices in stand-by mode.[4]

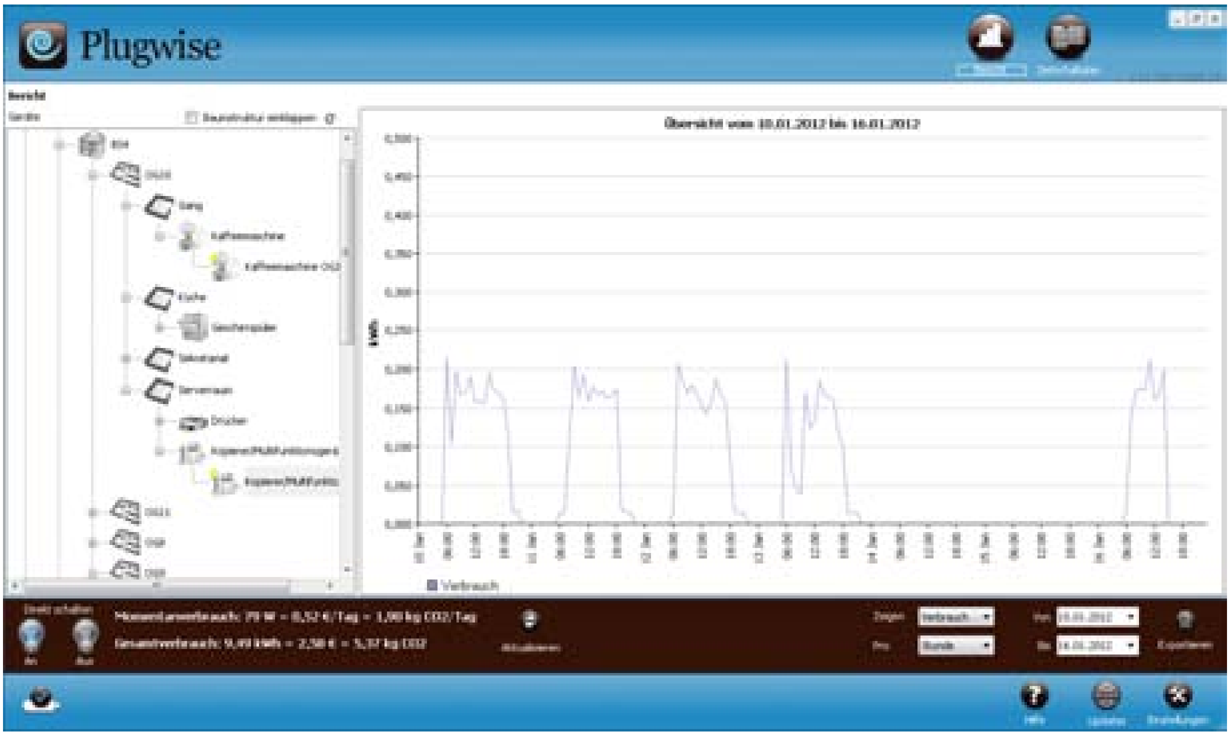


Figure 7 Screen shot from the PlugWise System

It turned to be a promising solution independent from human factor, but at the same time arousing users' interest in the scope of the energy consumption and savings. The employees showed interest in the system, especially in the detailed information on the energy consumption of the devices in normal operation and stand-by. Moreover the positive feedback was given to the possibility of definition of individual schedules for appliances.

Energy savings

The analysis of the energy consumption data before and after the implementation of the measures showed a reduction in the electrical energy consumption. The average electrical energy consumption after the implementation of the information and motivation campaign was about 5% lower than during the same period before the implementation. The savings increased to about 7% after the implementation of the measures for the heating system which resulted in reduced use electrical heaters.

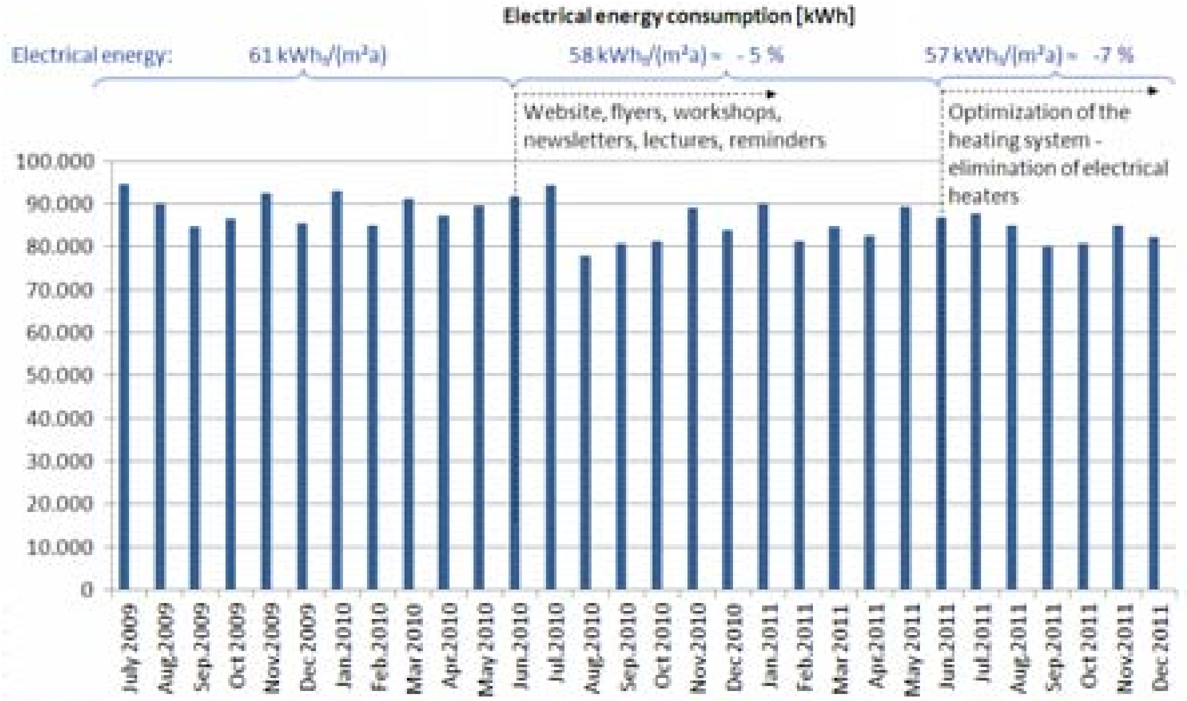


Figure 8 Electrical energy consumption in the Centre of Informatics before and after the implementation of the measures

The further potentials for reduction in the base load are to be verified with a PlugWise system. The trial done in three institutes in the Centre of Informatics showed that the appropriate schedule for automatically turning off of the office equipment can entirely eliminate energy waste related to stand-by modes during nights, breaks and weekends. The potential for savings in the building depend strongly on the proper selection of devices.

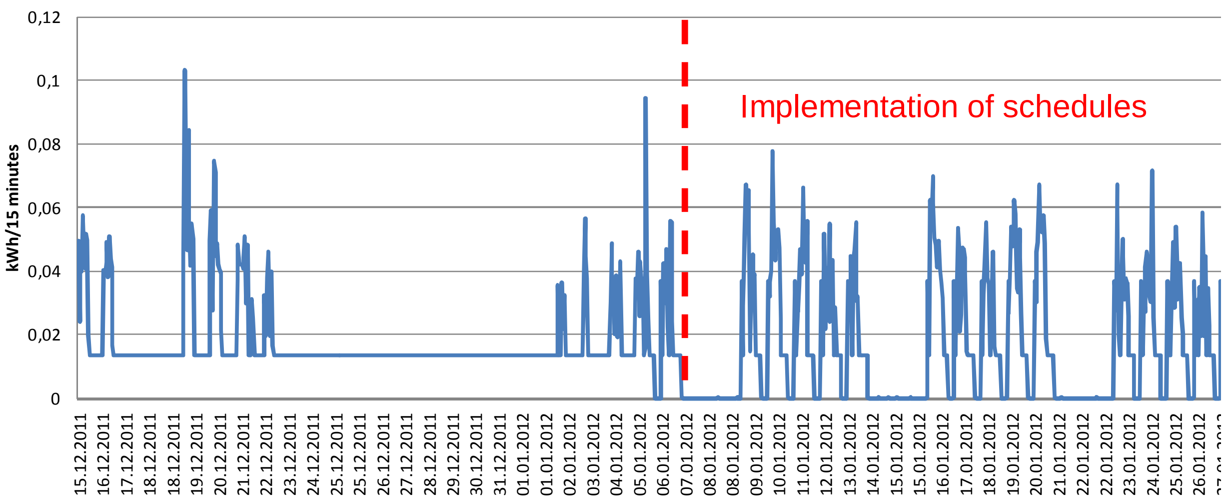


Figure 9 Electrical energy consumption in the office before and after schedule implemented

Saving heat turned to be a fragile issue since the user already felt uncomfortable in winter. Therefore it was impossible to involve the employees directly in the saving process, the optimisation plan was created and implemented. The building management supported the process of the preparation, evaluation and implementation of the technical measures for the enhanced system operation. The first measures brought reduction in heating energy consumption of about 5% compared to the preceding 12 months. Further savings are expected after the overhaul of the heating system which is scheduled for 2012.

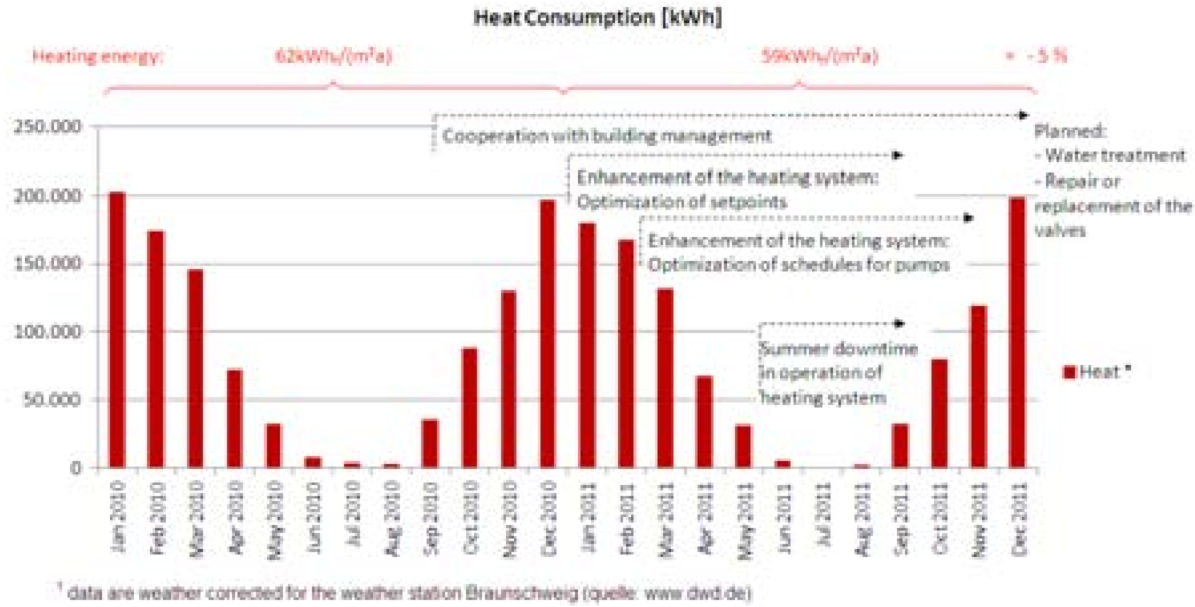


Figure 10 Heating energy consumption in the Centre of Informatics before and after the implementation of the measures

So far the overall demand of primary energy was reduced from 210 $kWh_{PE}/m^2_{NGF}a$ to 197 $kWh_{PE}/m^2_{NGF}a$, which is equivalent to a 6% reduction in primary energy consumption in the building after the implementation of the measures.

The further reduction in energy consumption will be achieved after the implementation of the measures designed and tested during the project and to be implemented on a large scale at the end of the project or immediately following it. The predicted changes will result into a 10-13% reduction in primary energy consumption, as well as in 12% reduction in CO_2 emissions.

Although it is impossible to precisely ascribe the fluctuations in the energy consumption to the measures carried out, the decrease is likely to be caused by the implementation of the project – no other relevant changes in the building or its management occurred during the running of the project.

Conclusions

The project demonstrated how various ICT solutions can support the optimization process in a buildings, by identifying technical saving potentials and by drawing users´ and the building managements´ attention to the energy performance of the building. Moreover an individual automated control of the operation of the appliances not only helps to avoid unnecessary energy consumption in stand-by mode, but also attract users´ attention to the issue of energy efficiency in the offices.

An additional result of the project was the numerous experiences with the implementation process of measures. The implementation of changes in behaviour was time consuming and showed the necessity for social abilities in change management. This task will be a focus of the Intelligent Energy Europe project Re-Commissioning that started 2011.

References

[1] Energieeinsparverordnung für Gebäude EnEV 2009

[2] Soldaty H., Plesser S., Fisch M.N., *Best Energy - Built Environment Sustainability and Technology in Energy,* http://www.xia-international-online.de/

[3] http://www.energynavigator.tu-bs.de/resy/

[4] http://www.plugwise.com/idplugtype-g/pro-50

Some Aspects of a Framework for Energy Data

Neil Brown, Rick Greenough, Konstantin Vikhorev

Institute of Energy and Sustainable Development, DeMontfort University, Leicester, UK.

Abstract

Little doubt exists that technologies for precisely, and automatically measuring energy use are timely. Pressure to reduce greenhouse gas emissions, the potential for a generation shortfall, and rising energy prices, modern building complexities, mean that estimating building energy use patterns, profiling of building energy use, and energy failure mode identification can help to maintain energy efficiency. However, further uses exist beyond operational management; These include urgently required meta-analysis of building stock by sector, up to national stock levels, to inform policymakers, since a dearth of national stock data exists at government level in many countries. Many existing systems use radio telemetry, often producing unclean data. Analysis of energy data for large datasets becomes expensive due to incompatible formats, hampering use of old data on new systems, and data from different systems should we acquire new data, or as we acquire physical buildings. We argue that a standard should include basic specifications for fundamentals such as date formats, but a secondary scalable layer will allow future-proofing of datasets for longitudinal study, and open the door to advanced analysis techniques such as complex event processing. Disaggregation to plant level, as well as building related activities, such as manufacturing activity, also becomes possible with a scalable data structure. This paper, proposes a framework for an energy data standard from a data analysis perspective built around four areas: Temporal, accuracy & precision, operational and energy documentation.

1. Introduction

In the UK, 44% of total national energy use is consumed as part of activities within buildings as reported by UK Government [1]. Advanced metering gathers building energy data remotely without requiring site visits (typically half-hourly) [2], and is increasing in use due to market pressures [3]. It is mainly currently used for billing purposes, although offers very useful datasets to study energy use [4-5]. It offers massively streamlined and enhanced opportunities for identifying energy savings [6]: It has been found that building control faults can be identified [5, 7] causing building services to run unnecessarily (e.g. over-cooling, unoccupied heating), in some cases up to 30% of an estate showing unoccupied (night or weekend) heating [4-5]. Electrical baseloads can be identified, and reduced by up to 20% [8]. Meta analyses are also possible to gauge the energy efficiency of entire commercial sectors [9]. Analysis of these data offers a potentially massive benefit to building users, designers, utilities and policymakers in understanding building energy wastage [5-6, 10-13]. It becomes clear that the uses of high frequency energy data are numerous, yet a common problem has been one of compatibility between datasets, data quality, and completeness as identified in VDI 4602 [14].

Energy management standards are becoming well documented, showing procedures and performance metrics [14-15], and energy efficiency prognosis [16]. Data interchange standards ensure reliability of telemetry systems in diverse applications, However, converting between formats is time consuming, and there is a major reliability issue, due to inconsistencies in documentation, and data quality [5]: When analyzing meta datasets, inconsistencies become clear in even methods of notation for such fields as building addresses [4], or metering point numbers, such that results (and their input to government policies) may be skewed by e.g. data duplication and double counting. Also, critical data may frequently be ignored, because inadequate documentation formatting means that a database server is not capable of processing it. Data quality issues arise since radio telemetry systems are not 100% reliable, and data may contain gaps, or artifacts from transmission inconsistencies [4]. To make matters worse, it's fairly standard practice to interpolate between missing data points to continue with analysis, but no agreed method exists for indicating that modified data is used in profile analysis. As new techniques emerge for energy data analysis [11], a consistent data format and inbuilt functionality for checking data quality lends itself to automated processing [6, 11-12]. Compatibility, over time becomes an issue such as when a supplier of advanced metering hardware and software changes their own data structure. A basic framework for an energy data interchange standard, albeit at a higher level of abstraction, but broadly functionally similar to a standard such as BS EN 61850-7-420:2009 [17], is needed to ensure sideways, and forwards and backwards compatibility.

2. Existing Data Standards

Clearly the issues surrounding an energy data standard at first glance appear incredibly complex, but they fall into four main areas: Temporal (e.g. time and date issues, handling time driven data errors), Accuracy and Precision (including sensing devices and energy data quality), Data documentation (e.g. multipliers for kWh, building zones), and operational documentation (e.g. known down-time, data transmission issues). A literature search has revealed existing approaches which address at least in part some or most of these areas:

The International Standard for spectral data exchange [18] gives a good example of a data structure . specifically aimed at complex data transmission. For example, timestamp formats are specified as DD-MMM-YYYY, HH:MM (exactly the kind of detail, not currently made standard in many energy datasets). We must remember that timestamps are likely to require resolution down to seconds, (e.g. advanced building controls, PV monitoring, energy data rates used for manufacturing), and we must ensure, or at least be sensitive to compatibility with week numbers. The International standard 8601 [19] allows us a portable method of representing dates and times including these, as well as time intervals. (It could be argued that when dealing with, for example half hourly data, the sensible approach taken in manufacturing of representation by week numbers circumvents the perennial problem of processing date of the calendar months. Many of which have different lengths). Crucial at this phase is to specify the accuracy and precision of timestamps, and latency as in EN 61970-407:2007 on time series data access [20]. Following on from timestamps, there may be periods of non-transmission and we need a standard method of reporting this. This would require similar error codes to those described in BS EN 60255-24:2001 [21].

Low-level data transmission as described effectively in BS 15231:2006 on data communication in building automation [22], shows how reporting of transducer types (such as fiscal meters or current transformers), and equipment status is carried out using appropriate keywords. The standard contains appropriate codes for phenomena such as power, power factor, current and voltage, and fiscal meters may be treated as a credible reference since they offer stability, precision and accuracy suitable for billing [23] indeed, it is possible to specify measuring procedure down to appliance level as in ISO 12174:2003 [24].

It becomes clear that an extensible data structure offers clear advantages, notably for disaggregation down to plant level. The draft BS EN 62714-1 Engineering data exchange format for use in industrial automation systems engineering [25] offers a way into appropriate descriptors, albeit to describe hierarchies of manufacturing elements as part of a production line. Just as the Celenec report CLC/TR 50403 [26] represents supply-side disaggregation, it seems clear that an extensible way of representing hierarchies is ideal for representing disaggregated energy data. An extensible data structure with event reporting capability is described in three standards [20, 27-28], which while aimed at supply-side electricity distribution, comes very close to an appropriate system for energy event reporting, hierarchy descriptors within buildings, etc. Taxonomies also exist for room and building use types, enabling profile comparison, or to examine more precisely, energy use by sector, and an appropriate link should be documented. It may be also necessary to represent building physics, and appropriate date for performance evaluation (such as degree day calculation, climatic data [29]). Clearly a useful set of standards already exists (often with some overlap), but this is currently in a fragmented state when looking at data analysis for energy and buildings. A new standard structure can build on this useful work.

3. Energy Data Entities

A possible cause of slow development of a data standard is that solutions have largely been developed in-house by software companies, with little perceived need for portability. Also the link has not been made, or disparities identified between the [level of] data complexity required by an energy manager and software provider, meaning underlying data structure is almost certainly not seen as important when purchasing energy data software. Clearly a dataset should address data portability between core energy data tables. It would arguably be a missed opportunity, to ignore routine peripheral data, such as building characteristics, plant, machinery, building use, and occupancy.

These wouldn't necessarily need to be described in as much detail, but a standard could and should make recommendations for inclusion of the types of documentation needed for analysis.

Figure 1 shows the entity relationships for a typical energy dataset. On first glance, these data may be complex to envisage, although when logically presented, we see that the data structure falls into four sections: temporal data, accuracy and precision of data, supporting documentation, and energy data documentation.

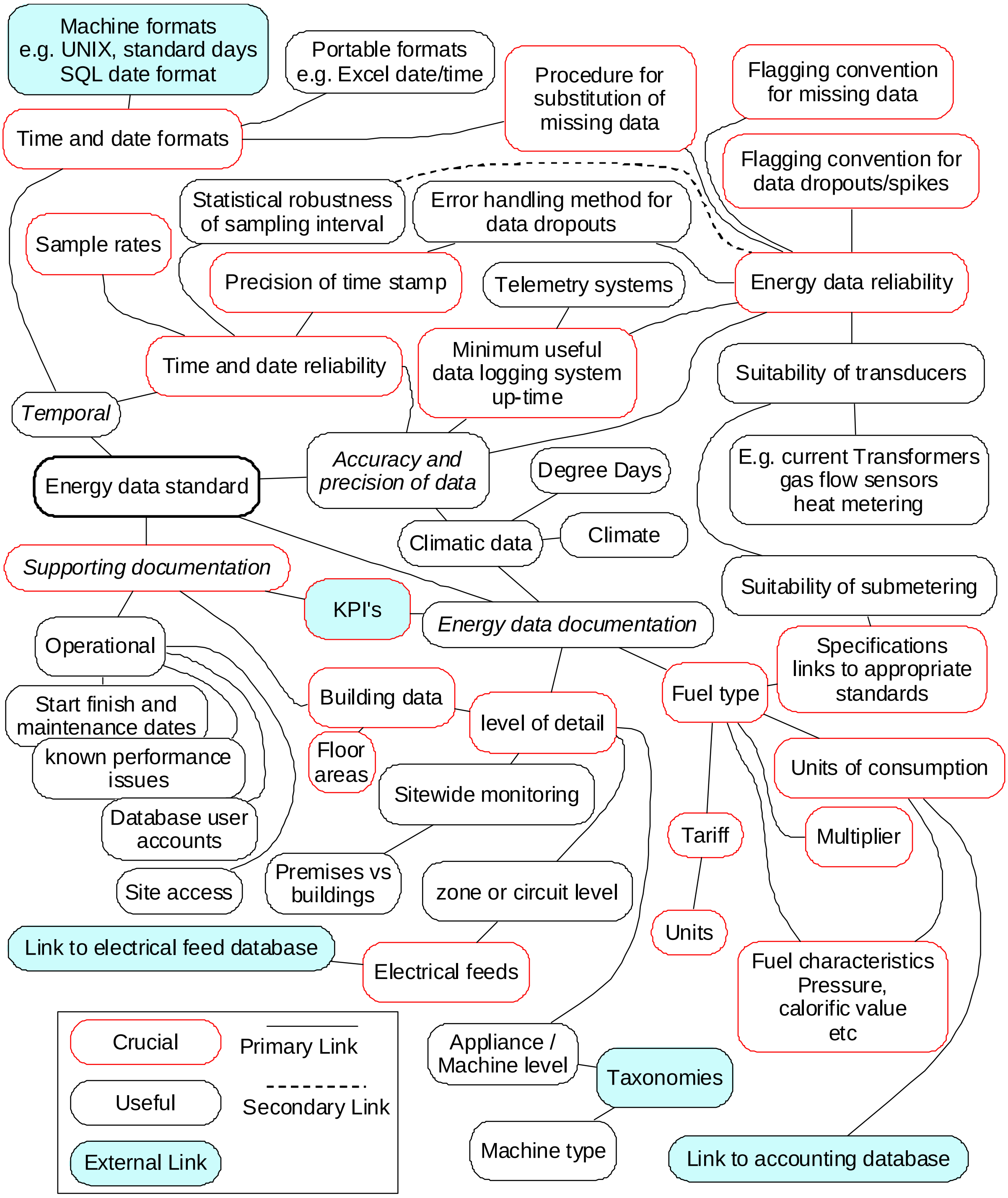


Figure 1. Entity relationship diagram for main components of an energy dataset

4. The four key aspects of a standard dataset in detail

The entities from Figure 1 may be distilled thus:

1. Temporal. Date formats, time stamping and sample rates, are important parts of energy data, which are often error prone, so some data may not be analysed. Often it is usual to substitute data from similar periods, or interpolation is used with some loss of detail [6]. A minimum level of acceptable data quality could be stipulated for time stamping in both reliability and precision, but also procedures must be put into place for handling of data errors, and logging such events. Basic telemetry systems reliability should ideally be stipulated, whereby should data dropouts cross a threshold, cleaning is abandoned in favor of corrective action on hardware or software.

2. Accuracy and Precision of Data. One shortcoming in conventional energy datasets, is that accuracy and precision of time stamping and energy data is rarely quantified. One upshot of this is that half hourly data may not be recorded on the half-hour, hampering analysis. The basic nature of (low power) electronics in conventional energy data loggers has been in the past such that errors can creep in to timestamps.

Transducer accuracy and precision is also important. For example, current transformers (CTs) for electricity monitoring, are unreliable for certain low currents, depending on CT peak load (in other words, a 400A CT may be unreliable at less than 10 amps). Clearly transducer specifications should be recorded, or at least useful operating range.

Climatic data is widely used calculation of predicted loads. The location of outside air temperature (and other weather) probes should be documented, also degree day algorithms.

In radio-based [including low-power radio and 3G based telemetry] is that where data transmission dropouts have occurred, local metering will continue to log integrated consumption until the channel for data transmission reopens. This produces in data, apparent zeros for energy consumption, followed often by a very large accumulated spike when transmission resumes. This hampers analysis considerably, but could be circumvented with a flagging convention, to allow skipping over faulty data, or to trigger data cleaning.

3. Operational Documentation – is required such as naming conventions from buildings, energy feed descriptors, and database specific operational data, as well as performance issues such as downtime for radio telemetry apparatus. Documentation should also be stored in one place, such as user accounts, permissions and privileges for database access, details of access to metered buildings or sites and scheduled maintenance of data gathering hardware and software.

4. Energy Data Documentation - Energy data documentation should be stored within the dataset, notably energy types (fuel types). (e.g. gas caloric values), and conversion factors to kWh. Any data structure must be open to the inclusion of tariff information, which also raises the possibility of data suitable for variable rate tariffs and load leveling.

Suggested data types for inclusion within an energy data structure

Sample datatypes are described below and expanded upon in Table 1 which have been used very effectively in the analysis of half-hourly data by the authors [4]. Since this paper is mainly from an energy data processing and software engineering perspective, these are offered as a point for debate, rather than the last word on a standard datasets contents. However, it is hoped that this gives a general indication of data types required for cross compatibility.

FT – Free Text. The free text data type, to describe for example, the types of telemetry systems used, or operational data such as database usernames. A very comprehensive standard could even dictate database table names to be used, and a naming convention for fields.

FN – Fixed number. A specification. e.g. ‘there should be no more than 3 missing data points in 168 hours data’. A fixed number, would be a specification - another example being: time stamping should be within X percent of an agreed value for accuracy and precision.

UV – User Value. User determined value (e.g. sample rate), which should be documented in the dataset. Another example would be calorific value of gas [30].

MP – Method or Procedure. (e.g. for flagging missing data, a recommendation is made that in a separate field, codes are used to distinguish between failure modes, and suggested codes are given), as well as certain practices for handling energy data handling. A perennial issue is data dropouts (caused by a gap in radio transmission), and a method or procedure would be stipulated for handling these. This may also for example suggest a method for interpolation or substitution. Flags should be set to indicate estimated data.

FM – Format. (e.g. for a date format, which standard format(s) to present e.g. mm/dd/yyyy hh:mm:ss, pivot year etc.) A data standard would be well within its rights to suggest formats for certain kinds of data, one perennial issue is the formatting of building information, such as date formats and site data. It can be argued that considerable time and money is spent unnecessarily in writing code merely to convert between formats for energy data, and date format processing forms a major part of this.

OD – Other Documentation, (e.g. scanned floor plans, wiring diagrams, factory layout, office electrical feeds.) Such documentation for data analysis should be included, or at least stored accessibly. Thiese would include for example, building floor plans or machine layout diagrams.

LK – Reference or link to other standards or documentation. Finally, references or links to other standards would be included in any comprehensive energy dataset, such as for example, a taxonomy of machine classes or types for analysis of energy consumption at individual machine level.

The following table is not a data dictionary, or an exhaustive list of data types which would appear in a standardised energy *database,* since data design is only represented at sub-context level. What it does represent is a workable grouping of core energy data types for a basic useful dataset. Links to other standards or references are crucial where cross-comparison of plant or machinery performance is required, (e.g. Key Performance Indicators) for comparisons within sectors usually considered beyond the scope of building energy analysis (such as efficiency of server farms, technical building services for factories, and ultimately appliance/subcircuit/machine use).

Area	Primary Subgroups	Secondary Subgroups	Subject for Standard and data type	Relates to
1.Temporal	1.1 Time and Date Reliability 1.2 Time and Date Format	------------------ ------------------	1.1.0.1 Sample rate UV 1.1.0.2 Precision of Timestamp FN 1.1.0.3 Substitution of missing time data MP 1.2.0.4 Machine formats FM 1.2.0.5 Portable formats FM 1.1.0.4 Statistical Robustness of Sampling Interval FN	2.1.1.3 Substitution of missing energy data
2. Accuracy and Precision of Data	2.1 Minimum useful system up time	------------------ 2.1.1 Energy Data Reliability	2.1.0.1 Telemetry Systems MTBF, design life. FT, FN 2.1.1.1 Flagging Convention for Data Spikes MP, FM 2.1.1.2 Flagging Convention for Missing Data MP, FM 2.1.1.3 Substitution of missing energy data MP 2.1.1.4 Suitability of Transducers MP,FX 2.1.1.5 Suitability of Sub metering MP, FX	1.1.0.3 Substitution of missing time data
3. Operational Documentation		------------------	3.0.0.1 Storage of start, finish, maintenance dates. MP, FM 3.0.0.2 Known performance issues. FT 3.0.0.3 database user accounts. FT 3.0.0.4 site access. FT	
4. Energy Data Documentation	4.1 Level of Detail	4.1.0 building data 4.1.1 Site wide	4.1.0.1 Building physics, UV, LK 4.1.0.2 floor areas, UV 4.1.1.1 premises vs. buildings, FT, OD	

		monitoring 4.1.2 Zone or circuit level 4.1.3. Appliance or machine level	4.1.2.1 electrical feed database , OD 4.1.3.1 taxonomies , FT 4.2.0.1 fuel characteristics, FM, MP, FT, LK 4.2.0.2 Tariff and tariff Units 4.2.0.3 Multiplier, UV	
	4.2 Fuel Type	------------------	4.3.0.1 Key performance indicators, LK 4.4.1.1 Degree day data, FM 4.4.1.2 degree day data standards, LK	
	4.3 KPI's	------------------	4.4.1.3 degree day calculation methods, LK	
	4.4 , climatic data	4.4.1 degree days 4.4.2 other climatic data	4.4.1.4 outside air temperatures, FM 4.4.2.1 links to other data and standards for e.g. wind speed and direction, precipitation, humidity, etc. LK	

Table 1. Energy datatypes

Discussion

A basic data structure is proposed which offers the software engineer, the energy manager, and ultimately a standards body a 'way in' to constructing compatible energy datasets. Clearly an extensible structure is required to add extra data where appropriate. The next step must be cooperation between all interested parties to achieve consensus on energy data for portability, functionality, and quality. While this paper looks at energy data from an operational and software engineering perspective, other analysts in the field may notice gaps or improvements in functionality:

These may include modelers of non-domestic stock energy, who may use energy data for compiling statistics on energy use by sector, whereby it is emergent that bottom-up modeling provides a solution to analysis of disparate stock, not least because of small sample numbers when grouping building use by type, where disaggregation by zone use within buildings enables more effective cross-sector comparison. An example is the analysis of UK manufacturing data which are based on small sample numbers when looking at vertical sectors [9].

Many analysis techniques commonplace in manufacturing are finding application in energy analysis [6], and additional data may be required to describe, for example, production schedules, and machine types. As exergy analysis becomes more popular too, more data will be required to describe fuel types, and material throughput, from office supplies to manufactured items, all of which affect energy use in commercial buildings, not least by effects on technical building services.

As analysis techniques mature, we must be mindful that techniques such as AI, spectral analysis and complex event processing will place more exacting requirements on data quality and documentation. Finally and topically, manufacturers who increasingly see energy as a manufacturing process variable, will be looking to improve compatibility between manufacturing data systems and energy data systems.

Conclusions

The idea that four main areas should be of importance when designing energy datasets has been stated, these being temporal, accuracy and precision of data, operational and energy supporting documentation. We have described some of the intricacies of a core dataset for building energy analysis, and some aspects of data which must be documented for enhanced functionality, not least to describe in more detail energy use patterns caused by activities within buildings. A data design model has been presented as an example for a portable energy dataset.

The benefits for carbon reduction from the currently fairly basic analysis of advanced meter data are considerable. As analysis becomes more precise and datasets expand, analysis will become more problematic, yet still offer considerable insights into energy saving opportunities. Issues of compatibility, reliability and accuracy within datasets if addressed would mean that potentially useful data need not be abandoned. As advanced meter data becomes more widely available, it seems clear that cross compatibility between datasets will be highly beneficial to analysts, energy managers, software vendors, and ultimately utilities and policymakers.

References

1. DEFRA, *e-Digest Statistics about: Climate Change*. 2006.
2. Lunzer, H., *Intelligent metering.* 2007 5th Ieee International Conference on Industrial Informatics, Vols 1-3, 2007: p. 1215-1219
3. Stephenson, P. and M. Paun, *Consumer advantages from half-hourly metering and load profiles in the UK competitive electricity market.* Drpt2000: International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, Proceedings, 2000: p. 35-40
4. Brown, N., Wright, A.J, *DELIVERABLE 15. Report on Half-Hourly Metering Profiles* 2008, Instititute of Energy and Sustainable Development, DeMontfort University, Leicester, LE1 9BH, UK.
5. Brown, N., et al., *Longitudinal analysis of energy metering data from non-domestic buildings.* Building Research & Information, 2010. **38**(1): p. 80 - 91.
6. Brown, N., Wright, A.J, *New Approaches to the Gathering, Analysis and Interpretation of Half Hourly Energy Metering Data from Buildings.* International Journal of Low Carbon Technologies, 2007. **2**(1).
7. Younger, W., *Using interval meter data for improved facility management.* Energy Engineering: Journal of the Association of Energy Engineering, 2007. **104**(5): p. 21-33.
8. Brown, N., et al., *Novel Instrumentation for Monitoring After-Hours Electricity Consumption of Electrical Equipment.* Energy and Buildings, 2011.
9. Liddiard, R., *Characterising Space Use and Electricity Consumption in Non-domestic Buildings*, in *Institute of Energy and Sustainable Development*. 2012, DeMontfort University: Leicester, UK. p. 218.
10. Stuart, G., *Monitoring Energy Performance in Local Authority Buildings*, in *IESD*. 2011, DeMontfort University: Leicester.
11. Ferrera, V., *The analysis of primary metered half-hourly electricity and gas consumption in municipal buildings* in *IESD*. 2009, DeMontfort University, Leicester. Instituto Superior Técnico, Lisbon.
12. Stuart, G., et al., *Rapid analysis of time series data to identify changes in electricity consumption patterns in UK secondary schools.* Building and Environment, 2007. **42**(4): p. 1568.
13. Wright, A.J., Brown, N., *The Analysis and interpretation of half hourly utility data in UK buildings.*, in *Fourth International Conference Improving Energy Efficiency in Commercial Buildings*. 2008: Frankfurt.
14. Anon, *VDI 4602 Energy Management Standard: Energy Management. Terms, definitions*. 2007.
15. Mse, A., *A Management System for Energy*. 2008.
16. Chu Pulido, H.A. and I. Sanchez Ramos, *Present conditions and perspectives of the standardization of the energy efficiency in Mexico; Actualidad y perspectivas del programa de normalizacion de la eficiencia energetica en Mexico*. 1999.
17. ECS, B., *BS EN 61850-7-420:2009 Communication networks and systems for power utility automation. Basic communication structure. Distributed energy resources logical nodes.* 2009.
18. ISO, *ISO 22029: Standard file format for spectral data exchange* 2003.
19. ISO, *ISO8601: Data elements and interchange formats Information interchange Representation of dates and times*. 2003.
20. BSI, *BS EN 61970-407:2007 Energy management system application program interface (EMS-API) Part 407: Time Series Data Access* 2007.
21. BSI, *BS EN 60255-24:2001 IEC 60255-24:2001 Electrical relays Part 24: Common format for transient data exchange (COMTRADE) for power systems*. 2001.
22. BSI, *DD CEN/TS 15231:2006 DRAFT FOR DEVELOPMENT Open data communication in building automation, controls and building management Mapping between Lonworks and BACnet*. 2006.
23. BSI, *PD CEN/TR 16061:2010 Standards Application - Gas meters - Smart Gas Meters*. 2010.
24. ISO, B.E., *BS ISO 12174:2003 Space data and information transfer systems. Telecommand. Architectural specification for the data management service.* 2003.

25. BSI, *Draft BS EN 62714-1 Engineering data exchange format for use in industrial automation systems engineering (AutomationML) - Part 1: Architecture and General Requirements*. 2012.
26. CENELEC, *TECHNICAL REPORT CLC/TR 50403 Standardization and the liberalization of the energy market* 2002.
27. ECS, B., *BS EN 15232:2007 Energy performance of buildings. Impact of building automation, controls and building management.* 2007.
28. BSI, *BS EN 61970-405:2007 Energy management system application program interface (EMS-API) - Part 405: Generic eventing and Subscription (GES)*. 2007.
29. BSI, *BS EN ISO 15927-4:2005 Hygrothermal performance of buildings Calculation and presentation of climatic data Part 4: Hourly data for assessing the annual energy use for heating and cooling*. 2005.
30. ECS, B., *BS ISO 15112:2007 Natural gas. Energy determination.* 2007.

Monitoring of energy use in a Swedish shopping mall

Sofia Stensson and Per Fahlén

SP Technical Research Institute of Sweden

Abstract

This paper presents results and lessons learned from an energy auditing campaign of a shopping mall situated in Sweden. It has an approximate floor area of 20 000 m^2. Heating and cooling is provided by means of electricity through local boilers and chillers. The ventilation system is a variable air volume system with heat recovery by enthalpy wheels. Chilled beams are used for supplementary space cooling. The shopping mall has been carefully monitored since 2006 and monthly data of purchased energy from 67 electricity meters are presented in this paper. A complementary measuring campaign was carried out on two occasions, one in summer and one in winter. In this campaign, data from the cooling plant and the ventilation system were gathered from the building automation system concerning temperatures, pressures, valve operation, fan operation, and electric boiler operation. The two measuring periods lasted for ten days and data were sampled every 15 minutes. Load patterns from people, lighting, equipment, insolation and weather conditions were investigated. A measuring system was used for counting the number of visitors to determine the occupancy pattern.

The results from the study showed that the yearly purchased electricity is 204 kWh/m^2, including both landlord and tenant electricity. The energy use is analysed and compared to national Swedish energy statistics. This benchmarking shows that there are problems with the currently used definitions and how they should be interpreted. Therefore, there is a need for improved benchmarking methods including comparable key performance indicators.

Introduction

From an energy point of view, a building forms a system of interacting parts and components. When developing new technologies it is always necessary to analyse the effects on the total energy use of the building. For instance, focusing on thermal energy only in low-energy building studies, without taking into consideration what happens with the requirements of electrical energy, can be questionable. Without sufficient information about the influence on both thermal energy use and electrical energy use, there is an obvious risk of misleading conclusions.[1]

This study presents an energy auditing campaign of an existing shopping mall situated in Sweden. In this shopping mall purchased electricity has been carefully monitored since 2006. But there has not been any measuring of the thermal energy use. In order to analyse the total energy use of the shopping mall, also including heating and cooling demands, a simulation model was developed using the software program BV2. The theoretical framework for the BV2 model was originally developed and presented in a doctoral thesis by Nilsson[9]. The BV2 model has been validated by calculations and analyses carried out with DOE-2 simulations. The BV2 version 2010 has also been validated according to IEA Bestest[7]. The name BV2 comes from the Swedish "Byggnadens Värmebalans i Varaktighetsdiagram", or directly translated to English "the building heat balance in duration diagrams". A purpose of the BV2 model is to be practically suitable for planning of commercial buildings, which is why it was chosen for this study of an existing shopping mall.

A few papers presenting energy use in shopping malls have been found published by Lam and Li[8], Busch[2], and Canbay[4]. However, neither of these studies makes a complete analysis of both the electrical energy use and the thermal energy use. The focus is always on the energy supply rather than the energy use. However, the need for comprehensive studies is becoming increasingly important, if the actual heating and cooling demands of buildings are to be understood. Studies shows that rising internal loads and improved building envelopes have resulted in major cooling demands even in a Nordic climate.[5] Load and demand are closely connected. A heat load will result in a corresponding cooling demand and vice versa. This correlation is partially illustrated in this paper.

In commercial buildings the heating demand is a minor problem today, according to Abel[1]. The main questions today are removal of surplus heat and removal of airborne pollutants. The need for energy for air treatment, space cooling and operation of fans and pumps is dominant. Also, the need for electricity for lighting and equipment forms a major part of the total energy. This energy is part of the tenant energy use, which is unfortunately excluded in the Swedish interpretation of the energy performance and building directive (EPBD).

Method

In this study, energy data available for an existing shopping mall have been analysed. The climate inside a building is the result of a complex interplay between the building envelope, the activities inside it and the outdoor climate. Energy flows and energy conservation opportunities (ECOs) will directly depend on this interaction and the set values for the indoor climate. Therefore, any analysis of the effect of energy conservation measures must be based on the total energy balance of the building. To capture this interplay and to understand the cooling and heating demands of the building a simulation model of the shopping mall was developed in the software program BV2 (for more information about the program the manual is referred to[3]). All purchased electricity to the shopping mall has been measured since 2006, except for tenant electricity which has been measured since 2008.

An extensive foundation of input data was gathered from the energy auditing and used in the simulation model. This section explains the compilation of input data to the model and assumptions made during calculations. Input data have been gathered from the following sources of information:

- Building and HVAC system plans
- Interviews with management and operative personnel
- Documentation of control strategies
- Mandatory ventilation inspection protocols (in Swedish OVK-protokoll)
- Data from the building management system
- People counting systems
- Measured purchased electricity

Purchased electricity interpretation to BV2

The purchased electricity, presented in Figure 1, is based on the years 2008-2010. The building owner measures the purchased electricity and stores monthly data in a data base. These data come from 67 electricity meters. An interesting fact with this shopping mall is that the tenant electricity is known, since there is a separate electricity meter to each shop. Usually the shops have their own electricity agreement, and the total tenant electricity is therefore not known.

The total purchased electricity to the shopping mall is 204.7 kWh/m^2/year. As seen in Figure 1 this electricity is divided between the electricity users as follows; chillers 6 %, electric boilers 7 %, ventilation 12 %, other landlord electricity 22 % and tenant electricity 53 %. The purchased electricity does, however, not give information on the actual heating and cooling demand of the building. Therefore, building simulations are used to illustrate the theoretical heating and cooling demands.

To compare buildings with different size, the notation *specific energy use* is commonly used. This is defined as total energy use divided by the floor area of the building. When specific energy use or specific purchased energy, kWh/m^2, is compared it is important that the same areas are compared. Just to illustrate the different area definitions those are being used the most common Swedish definitions are listed as an example:

- Atemp: Floor area in temperature regulated spaces that are planned to be heated to a temperature above 10 °C.
- BRA (in Swedish: bruksarea): The sum of all areas of all floors measured from the inside of the building envelope.
- BTA (in Swedish: bruttoarea): The sum of all areas of all floors measured from the outside of the building envelope.
- LOA (in Swedish: lokalarea): Rentable are in non-residential buildings or areas for building operation and communication.

Different definitions are not analysed in detail, the aim here is only to highlight the need for consensus. In order to achieve comparability between countries harmonisation of the area definition and their use is desired. The area that has been used in this paper is Atemp, which should be noted if the results from this paper are to be analysed with specific energy use of other buildings.

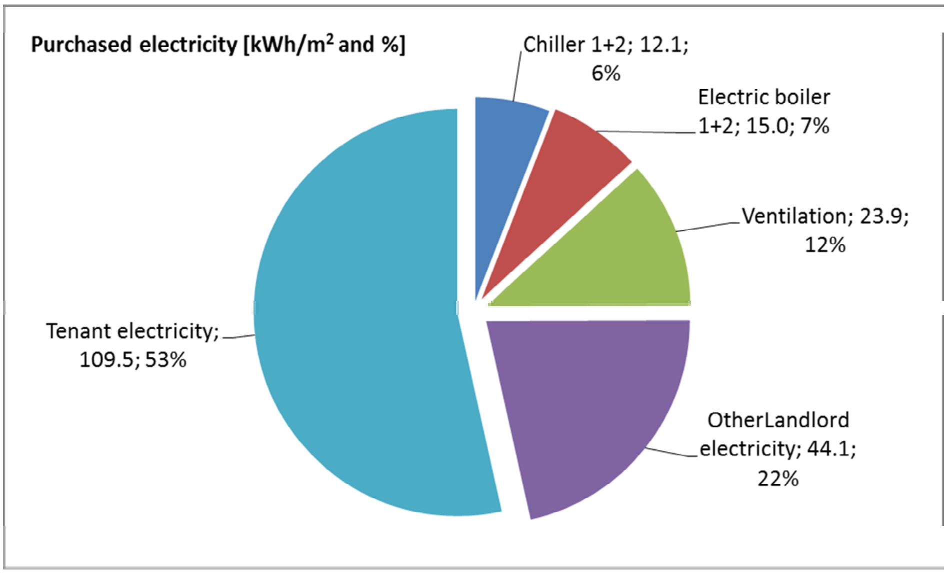


Figure 1 **Purchased electricity divided between chillers, electric boilers, ventilation, landlord electricity and tenant electricity.**

The measured purchased other landlord electricity and tenant electricity are used as input to the simulation model. The measured purchased electricity to chiller 1+2 and ventilation are used to compare the result of BV2 with the measured data. In this study the assumption is made that the tenant electricity is used exclusively to lighting and the landlord electricity to building services. Measured purchased electricity to Chiller 1+2 is assumed to be the same as “Chiller electricity for cooling to chilled beams and AHU cooling coils in” BV2. Purchased electricity to ventilation is assumed to be the same as electricity to fans in BV2. An overview of the interpretation of the measured purchased electricity used as input data to BV2 is given in Table 1. The other landlord electricity is assumed to go to equipment. Example of equipment in a shopping mall would be lifts, escalators etc.

Table 1 **Interpretation of the measured purchased electricity and overview of input and output data to and from BV2.**

MEASURED PURCHASED ELECTRICITY	ELECTRICITY IN BV2	Measured purchased electricity [kWh/m²/year]	Used as input data to BV2	Compared output data from BV2
Chiller 1+2	Chiller electricity for cooling to chilled beams and AHU cooling coils	12.1		X
Tenant electricity	Lighting	109.5	X	
Other landlord electricity	Equipment	44.1	X	
Ventilation	Fans	23.9		X
Heating	Electric boilers	15.0		X

The main input data concerning internal heat generation, construction and HVAC system are presented in Table 3 to Table 10. It must be remembered that, regardless of how detailed and physically correct a simulation program is, the quality of the output data that it produces cannot be better than that of its input data[9]. The resources for collecting and evaluating the input data for this study have been limited. However, the principle analysis concerning the simulation results should still be valid.

Internal heat generation

To calculate the power from the internal heat generators (lighting, equipment and people) the shopping mall open hours are used. The shopping mall open hours are shown in Table 2. The total number of open hours during one year is 3016 hours.

Table 2 Shopping mall open hours.

Monday to Friday	10:00-19:00
Saturday	10:00-17:00
Sunday	11:00-17:00
Total number of open hours during one year	**3016 hours**

Table 3 shows the input data to the simulation model concerning heat generation. The shops in the shopping mall consist of retail trade such as clothing, shoes, cosmetics etc. where electricity to a large proportion goes to lighting, which is why all tenant electricity, 109.5 kWh/m^2, in this case can be assumed to go to lighting. The average lighting power would then be 36.3 W/m^2. According to the measured purchased electricity, other landlord electricity amounts to 43.9 kWh/m^2. If all this electricity is assumed to go to equipment during the open hours of the shopping mall, then the average equipment power would be 14.6 W/m^2. The value of the specified heat for people in BV2 contains only the sensible heat, which is the heat that directly affects the heat balance of the building. Latent heat submitted by people as water vapour is assumed not to affect the heat balance in BV2. This is true as long as there is no need for dehumidification of supply of room air. Based on results from the people counting system and occupancy profiles gathered from other shopping malls, the average heat from people is assumed to be 4.1 W/m^2.

Table 3 Input data to simulation model: internal heat generation.

Heat source [W/m^2]	**Day**	**Night**
Lighting	36.3	0
Equipment	14.6	0
Occupants	4.1	0

Construction

The case study building is a shopping mall situated in Sweden. Of the climate files in BV2, the file “Göteborg Säve” was closest to the case study building. The file includes hourly data from Gothenburg from the computer program metotest-Meteonorm 4.0, which is based on values of temperatures from 1961 to 1990 and the sun from 1981 to 1993. When there is no temperature difference between outdoor air and indoor air, i.e. no thermal force, the air leakage is set to 0.2 air changes per hour. When the temperature difference is 20 °C the air leakage is set to 0.4 air changes per hour. In BV2 it is possible to choose between light, average and heavy internal mass. In this case average was chosen.

Average temperature in the ground is usually set to the average mean outdoor temperature. In this case there is a parking garage and an office in the basement of the shopping mall. The parking garage is not heated but the temperature should anyway be assumed to be a few degrees higher than the average outdoor temperature for the geographical location, which for Göteborg Säve is 7.2 °C. The mean temperature in the parking garage is set to +10 °C. This is why the “Mean temperature in ground” in Table 4 is assumed to be +10 °C, which otherwise, without the parking garage, had been set closer to the average outdoor temperature.

Table 4 Input data to the simulation model: the building.

Climate file:	Göteborg Säve
Room height [m]	5.5
Air leakage, no thermal force [ACH]	0.2
Air leakage, thermal force at temperature difference 20 °C [ACH]	0.4
Volume [m^3]	110550
Inner mass	Average
Area on each floor, roof area and surface area against ground [m^2]	10050
Number of floors	2
"Weight" of roof construction	Heavy
U-value of roof [$W/m^2/K$]	0.25
U-value of surface area against ground [$W/m^2/K$]	0.05
Mean temperature in ground [°C]	10

The building is orientated so that the main entrance consisting of a large window facade is facing north-west. The window façade area ratio to the total wall area of the entire shopping mall is 17 %. The properties of the facades and windows are found in Table 5.

Table 5 Input data to the simulation model: The building facades and windows.

Variable	South façade	East facade	West façade	North façade
Wall area (including windows) [m^2]	2145	1095	1095	2145
Weight category for wall	Average	Average	Average	Average
U-value for wall [$W/m^2/K$]	0.23	0.23	0.23	0.23
Window area [m^2]	-	-	-	1300
Glazing proportion [%]	-	-	-	100
Solar factor	-	-	-	0.67
Outer shading	-	-	-	0
U-values for window [$W/m^2/K$]	-	-	-	1.9

HVAC system

The ventilation system is a variable air volume (VAV) system. The building is divided into six zones, each supplied by its own AHU, as illustrated in Figure 2. In each zone there are a number of shops. The shop with the highest requirement set the conditions for the heating, cooling and volume flow rate for that particular AHU. The main schematic of the AHUs is shown in Figure 3. Heat is recovered through enthalpy wheels with a temperature efficiency of 74 % (manufacturer's data). The supply air is conditioned by the cooling and heating coils in the AHUs and supplied to the shops via ducts. The fans are frequency controlled to maintain constant static pressure, 230 Pa for the supply air (at GP11) and 150 Pa for the exhaust air at (GP12).

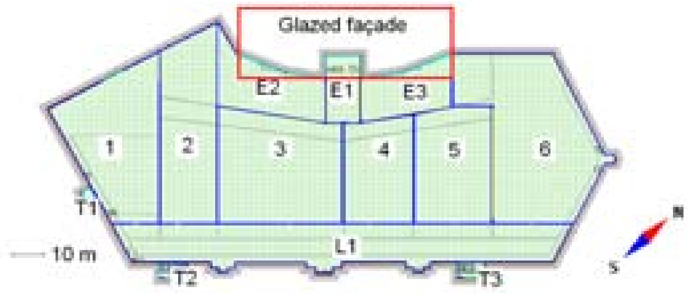


Figure 2 Sketch of second floor of the shopping mall. Ventilation zones are numbered 1-6. The zones on the first floor are similar, i.e. each of the six AHUs ventilates an area on both the first and the second floor.

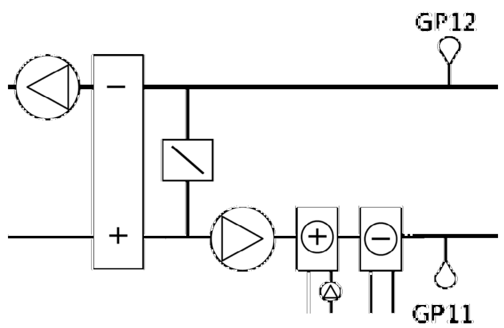


Figure 3 Principle schematic of one of the six AHUs.

The design volume flow rates for each AHU is found in Table 6. The rated power of the supply air fan and the exhaust air fan is 7.5 kW for each. The total design volume flow rate is 33.7m^3/s. The table also shows the operating time of the AHUs. At night time the ventilation is turned off. A comment to operating times of the fans is that if there are activities in the building generating moisture it is important not to turn off the ventilation too early. An example would be that if showers are used, it is important to ventilate to remove the moisture in order to avoid damage.

Table 6 Design volume flow rates for the AHUs (according functional control of ventilation systems).

AHU	Design volume flow rate [m^3/s]	Monday-Friday	Saturday	Sunday
AHU1	6.5	07:50-19:30	07:50-17:30	08:50-17:30
AHU2	5.3	07:55-19:30	07:55-17:30	08:55-17:30
AHU3	6.2	08:00-19:30	08:00-17:30	09:00-17:30
AHU4	4.2	08:05-19:30	08:50-17:30	09:50-17:30
AHU5	6.2	08:10-19:30	08:10-17:30	09:10-17:30
AHU6	5.3	08:15-19:30	08:15-17:30	09:15-17:30

The mean drive power input for ventilation is 20 kW as indicated in Table 7.

Table 7 Calculated ventilation operation

Operating time during one year [h/year] (total operation time for the 6 AHUs	3911 x 6 = 23465
Electricity to ventilation during one year [kWh/year]	471280
Mean power input [kW]	20.1
Specific electricity use for ventilation [kWh/m^2]	23.3

Table 8 Input data to the simulation model: indoor temperatures.

Lowest acceptable temperature [°C]	18
Set point value [°C]	22
Highest acceptable temperature [°C]	25

The ventilation system is a variable air volume system with heat recovery by enthalpy wheels. The total aggregated design air flow rate according to OVK-protocols for the six air handling units is 33.7 m^3/s, which corresponds to 1.6 litres/s/m^2

Table 9 Input data to simulation model: ventilation

Hygiene flow [litres/s/m^2] (BV2 chooses this flow rate)	1.6
Supply air temperature when the outdoor temperature is above 20 °C [°C]	16
Supply air temperature when the outdoor temperature is below 16 °C [°C]	16

The number of customers that visit the shopping malls during one day is approximately 6500. This implies that the person-specific flow rate becomes approximately 5 l/s/person. However, the customer will only be in the shopping mall for a short period of time and therefore the true volume flow rate per person is much larger.

The specific fan power (SFP) is not known. To calculate the SFP, the design volume flow rate and power use to the fans are needed. The design volume flow rate is known but the corresponding power to the fans is not. However, if the rated output of the fans is used instead of the power use at design volume flow rate an estimate of the maximum value is given and we know that the true value will be lower than that. The rated output of all the fans is 90 kW and the design volume flow rate is 33.7 m^3/s. This gives us that SFP cannot exceed 2.67 kW/(m^3/s) (90/33.7=2.67). Commercial buildings today have AHUs with SFPs within the range of 2-3 kW/(m^2/s). A possible value to aim for in the future is possibly closer to one.[6] The SPF is not known, therefore the BV2 default value of 3 is chosen.

Table 10 Input data to simulation model: Cooling.

Night operation	No
Recycling of cooling	Yes
Specific fan power, SFP [kW/(m^3/s)]	2.3
Efficiency of heat recovery [%]	74
Seasonal performance factor, SPF	3
Free cooling up to a temperature of [°C]	12

Simulated energy demand in BV2

Simulated thermal power and energy demand

According to the simulations, the heating power demand is 29.32 W/m^2. The heating energy demand is 21.99 kWh/m^2. Almost all heating energy is used during night,18.90 kWh/m^2. Most of the heat comes from heat recovery, 53.74 kWh/m^2, and the calculated power for the heat recovery is 46.86 W/m^2.

Assuming that all purchased electricity to the boilers becomes heating energy, the total purchased measured heating energy would be 15 kWh/m^2. The simulation model suggests that the heating demand is 21.99 kWh/m^2. This figure is however sensitive to the assumed infiltration. The simulation model will overestimate the heating demand if the air leakage is increased. For example if the air leakage at temperature difference 20 °C is set to 0.6 (instead of current 0.4) the simulated energy demand would almost double to 40 kWh/m^2.

Table 11 **Simulated thermal power and energy demand for heating.**

HEATING	Power [W/m²]			Energy [kWh/m²/year]		
	Day	Night	Design	Day	Night	Design
Radiators	0.00	21.05	21.05	0.00	17.73	17.73
AHU heating coils	11.55	0.00	11.55	2.26	0.00	2.26
Hot water	8.27	8.27	8.27	0.83	1.17	2.00
Total heating	**19.82**	**29.32**	**29.32**	**3.09**	**18.90**	**21.99**
Heat recovery	46.86	0.00	46.86	53.74	0.00	53.74

During day time more heating energy is supplied to the building via people and insolation 14 kWh/m^2, than from the heating system (3.09 kWh/m^2).Table 12 shows that there is storage of heat from day to night.

Table 12 **Internal heat from people and insolation**

INTERNAL HEAT	Power [W/m²]			Energy [kWh/m²/year]		
	Day	Night	Design	Day	Night	Design
People	4	0	4	10	4	14
Insolation	3	3	3	4	13	17
Lighting			36			110
Equipment			15			44
Total			**57**			**185**

The energy demand for cooling is 31.81 kWh/m^2, with the cooling power demand of 39.96 W/m^2.

Table 13 **Simulated thermal power and energy demand for cooling.**

COOLING	Power [W/m²]			Energy [kWh/m²/year]		
	Day	Night	Design	Day	Night	Design
Cooling supplied to chilled beams	12.86	0.00	12.86	13.99	9.39	23.37
Cooling supplied to AHU cooling coils	27.10	0.00	27.10	8.44	0.00	8.44
Total cooling	**39.96**	**0.00**	**39.96**	**22.43**	**9.39**	**31.81**
Cooling recovery	8.69	0.00	8.69	0.05	0.00	0.05

Simulated electrical power and energy demand

The measured purchased electricity to chiller 1+2 is 12.1 kWh/m^2, while the simulated electricity to the chillers is (7.79+2.81) 10.6 kWh/m^2. The measured purchased electricity to the ventilation is 23.3 kWh/m^2, while the simulated electricity demand to the fans is 13.43 kWh/m^2.

Table 14 Simulated electrical power and energy demand.

ELECTRICITY	Power [W/m²]			Energy [kWh/m²]		
	Day	Night	Design	Day	Night	Design
Chiller electricity for cooling to chilled beams	4.29	0.00	4.29	4.66	3.13	7.79
Chiller electricity for cooling to AHU cooling coils	9.03	0.00	9.03	2.81	0.00	2.81
Lighting	36.30	0.00	36.30	106.00	0.00	106.00
Equipment	14.60	0.00	14.60	42.63	0.00	42.63
Fans	3.68	0.00	3.68	13.43	0.00	13.43
Extra	0.00	0.00	0.00	0.00	0.00	0.00
Total electricity	**67.90**	**0.00**	**67.90**	**169.54**	**3.13**	**172.66**

Figure 4 show the simulated heating and cooling demands in duration diagrams. The annual cooling demand is proportional to the blue areas and the annual heating demand is proportional to the red area. These diagrams also show the direct cooling, which is not included in Table 13.

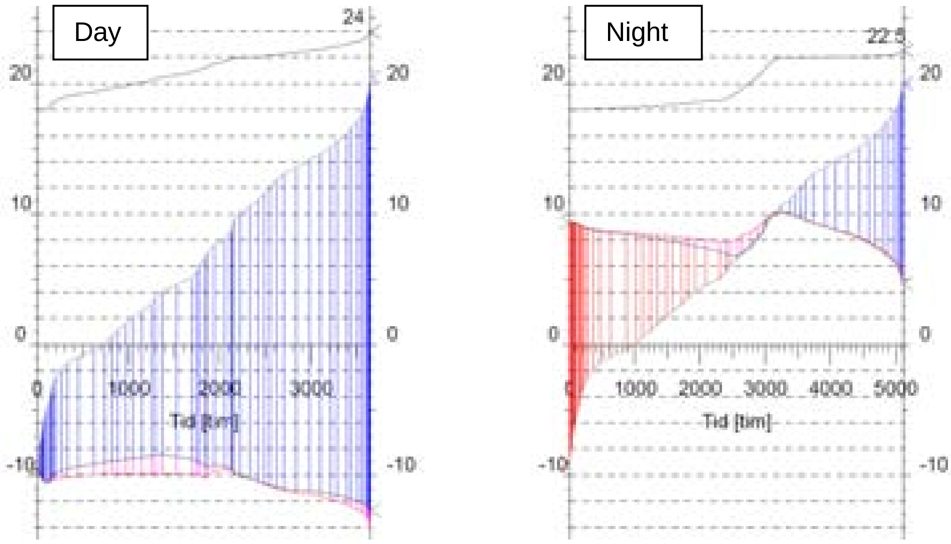


Figure 4 **Duration diagrams for day and night.**

Measured energy use

Measured thermal power and energy use

It would have been beneficial if thermal power and energy use were measured. However, there are unfortunately no thermal energy meters installed in the case study building. Hence the cooling and heating demands have only been estimated in the building simulations so far.

Measured electrical power and energy use

Figure 5 illustrates the purchased electricity to the two chillers. For the assessment of the efficiency of the cooling plant the overall seasonal performance factor (SPF) is desired. SPF gives an estimation of the capability of the system configuration. If the SPF of the cooling plant is to be determined then the cooling delivered from the chillers will have to be measured.

As can be seen in Figure 5 the chillers are only needed for cooling during half of the year. However, Figure 4 showed that there is a cooling demand throughout the whole year at day time. This means that when the chillers are not operating the cooling is cover by direct cooling.

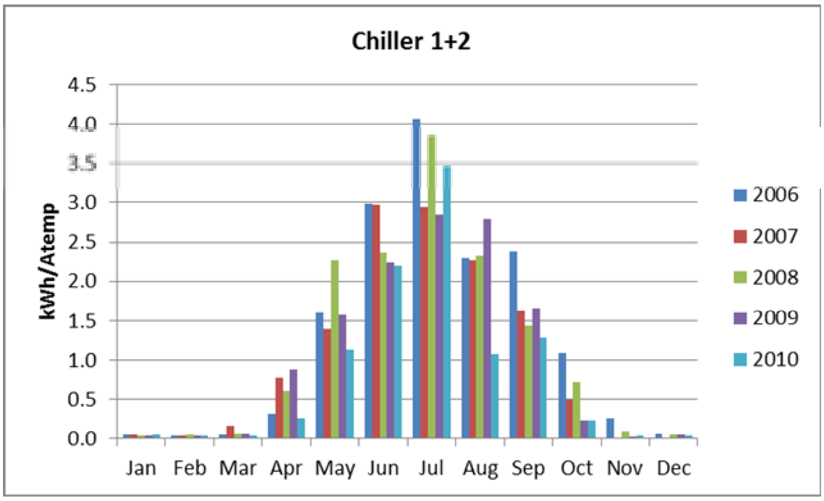


Figure 5 **Purchased electricity for the two chillers.**

Figure 6 illustrates the purchased electricity to the two boilers.

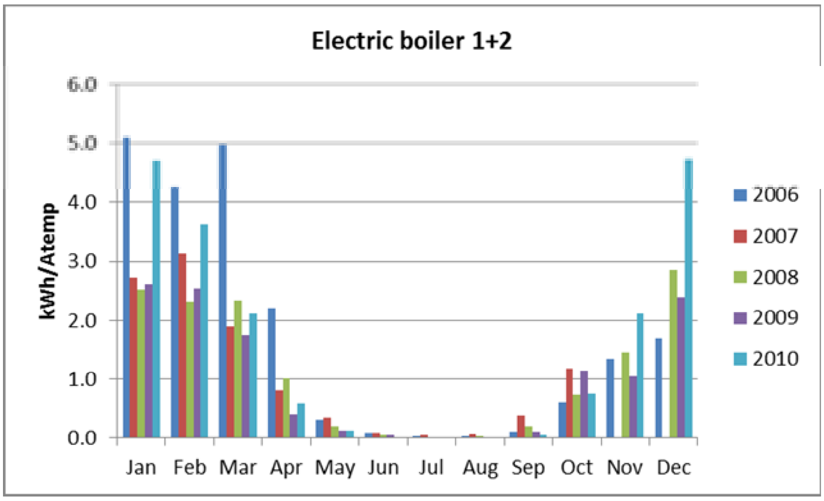


Figure 6 **Purchased electricity for the two boilers.**

Figure 7 illustrates the purchased electricity for the ventilation. In July 2006 considerably more electricity was used for ventilation. July 2006 was a relatively hot month for Trollhättan with an average temperature of 19.1, compared to the average temperatures varying between 17.8 and 18.7 for the years 2007 to 2010, according to data from www.temperatur.nu. In August 2010 the purchased electricity to ventilation is extremely low, the reason for this is unknown but it is possible that measurements are missing.

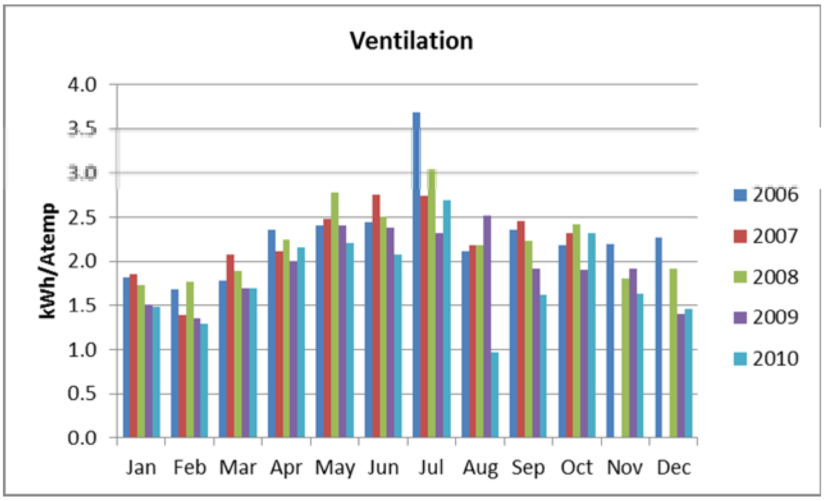


Figure 7 **Purchased electricity for the ventilation.**

Figure 8 illustrates the purchased other landlord electricity. Important equipment included in the other landlord electricity are two elevators, four lifts and two walkways.

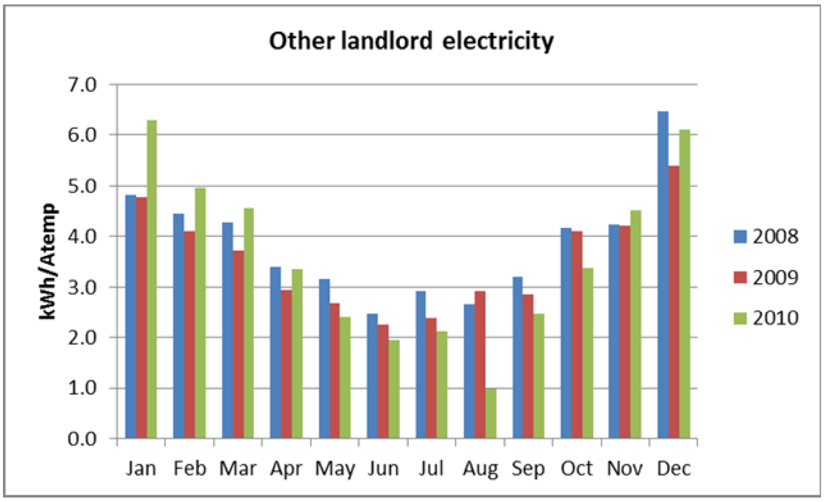


Figure 8 **Purchased landlord electricity.**

Figure 9 illustrates the purchased tenant electricity.

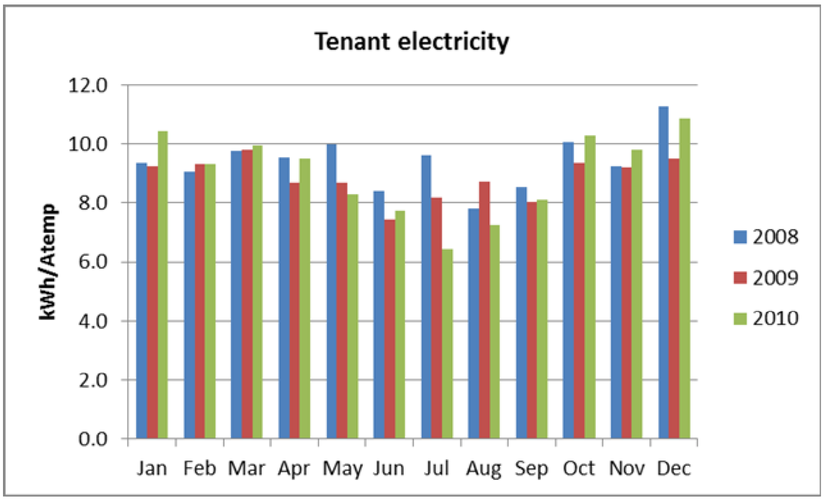


Figure 9 **Purchased tenant electricity.**

Discussion and conclusions

One lesson learned is, that in order to work efficiently with energy management, there is a need for improved measuring systems. Currently, purchased energy is measured and stored in a database. However, the purchased energy on its own gives no information on how the system is performing in detail. Data from the building automation system could also be stored. It would be useful for energy auditors with complementing measurements of, for example, temperatures and flow rates. Therefore, to improve similar energy audits, additional measurements are desired.

The purchased energies presented in this paper are divided according to an organisational division. The energy used for certain installations can be considered as either landlord electricity or tenant electricity depending on the ownership of the installation and the tenancy agreement. For the Building Energy Declarations, according to EPBD, tenant electricity is excluded in the mandatory declarations. Since tenant electricity includes different items depending on ownership and tenant agreement, it is difficult to use the results for benchmarking purposes. A functional division would have been better from the perspective of analysing the actual use of energy. Also, the electricity meters need to be broken down more, and the description for what is included in the respective measurements needs to be more precise. It would also be beneficial with additional thermal energy meters to get a better understanding of the heating and cooling demands of the building.

One of the conclusions from this study is that during daytime there is a cooling demand throughout the whole year, as shown in Figure 4. However, during the cooler half of the year the cooling demand is covered by direct cooling only, as indicated by Figure 5. These cooling demands and how they are handled are not that obvious in the traditional way of measuring only purchased energy supply, as shown in Figure 1. Therefore, this also proves the importance of understanding and of correct use of the terms purchased energy, energy supply, energy use and energy demand. These terms are too often mixed up and used inconsistently, making benchmarking an impossible exercise.

References

1. Abel, E., 1994. Low-energy buildings. (Energy and Buildings, vol. 21, nr. 3, pp. 169-174).

2. Busch, J. F., du Pont, P., Chirarattananon, S., 1993. Energy-efficient lighting in Thai commercial buildings. (Energy, vol. 18, nr. 2, pp. 197-210).

3. BV2 Byggnadens värmebalans i varaktighetsdiagram. Ett datorprogram för beräkning av byggnaders energibehov. Version 2010. Användarmanual. (In Swedish). 2010 Göteborg.

4. Canbay, C. S., Hepbasli, A., Gokcen, G., 2004. Evaluating performance indices of a shopping centre and implementing HVAC control principles to minimize energy usage. (Energy and Buildings, vol. 36, nr. 6, pp. 587-598).

5. Fahlén, P., Markusson, C., Jagemar, L., 2010 Influence of ventilation-system design on the use of heating, cooling and drive energy to fans. (Clima 2010, 10th REHVA World Congress.) Antalya, Turkey.

6. Fahlén, P., 2011. Comfort cooling with or without heat pump (in Swedish). Kyla, no. 7, 2011-11, pp. 32-38. (Kylentreprenörernas Förening.).

7. Judkoff, R., Neymark, J., 1995. International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method. US National Renewable Energy Laboratory.

8. Lam, J. C., Li, D. H. W., 2003. Electricity consumption characteristics in shopping malls in subtropical climates. (Energy Conversion and Management, vol. 44, nr. 9, pp. 1391-1398).

9. Nilsson, P.-E., 1994, Heating and cooling requirements in commercial buildings. A duration curve model including building dynamics. Göteborg.

Potential energy savings provided by HOMES solutions: from 25% to 50%

Olivier Cottet[1], Véronique Boutin[1], Magali Deschizeaux[2], Marc Altazin[3], François Bonnard[1], Didier Rys[4].

[1] HOMES programme – Schneider Electric; [2] HOMES programme - Watteco; [3] HOMES programme – CIAT; [4] HOMES programme – eDF

Abstract

The HOMES programme defined an innovative energy management and control strategy to reduce buildings' energy consumption. Simulation results using this strategy on real site models indicate very promising potential energy savings.

The principles of this strategy are: to reduce the energy demand in each room based on actual room occupancy while optimizing comfort, then to optimize energy supply in the three different energy vectors of the building to cater to these needs.

It presupposes the implementation in smart controllers of multi-application control solutions in each building's zones.

The HOMES programme assesses potential energy savings provided by this control strategy thanks to simulation tools, designed with data coming from 5 instrument-equipped real sites in France. The choice of the real sites covers a great diversity of situations, such as by usage sector, by, energy source for heating: by size; by age and thus by envelope qualities, and by climate zones.

For each site, two simulations have been performed, one reproducing as closely as possible the actual energy performance of the real sites, and the other representing the energy performance applying the control strategy with an equivalent or improved comfort situation.

The potential savings obtained range from 22% for the lowest (collective residential) to 56% for the highest (elementary school).

The HOMES program, thanks to its real site based pragmatic experience and to its thorough analysis of the European building stock, is now working towards making propositions for active energy efficiency solutions that can make a significant difference on existing European buildings.

Introduction

The HOMES (Homes and buildings for Optimized Management of Energy and Services) collaborative programme is designed to create solutions to achieve optimal energy performance in residential and commercial buildings in Europe both for new construction or existing building stocks.

The four-year (2008-2012) programme is supported by the French Agency for Innovation (OSEO) and led by Schneider Electric. Its thirteen members are manufacturers and researchers with synergistic expertise in building management: CEA, CIAT, CSTB, Delta Dore, EDF, Idea, Philips Lighting, Radiall, Schneider Electric, Somfy, STMicroelectronics, Watteco and Wieland Electric.

Its objective is “To equip each building with active energy efficiency solutions to achieve its optimal energy performance.”

Within this objective, the programme has three main areas of research:

- Information systems that permit building stakeholders - owners, occupants, service providers, technicians, managers - to make decisions that optimize a building's energy performance, and to experience energy behaviours. [1] [2]

- Tools and methods that allow the building actors to achieve an optimal design, easier construction and implementation, and efficient long term operation and maintenance.

- The optimization of the building and machinery functionning modes via controllers.

This article describes in the third area, the methodology adopted by the program, the control strategy defined and the protocol used to assess the potential of this control strategy on different existing sites: the five pilot sites of HOMES program.

Methodology adopted

Buildings are complex systems: they must provide different services (conditioned and comfortable environment, protection, security, allow movement and accommodate different activities, etc.), some of which require energy. They have many different technical systems and different light and thermal characteristics depending on their envelope; and are subject to variable environments (weather, presence of occupants, activities).

To design the optimum control for a building, this practical and operational complexity must be taken into account. Our methodology was to start with a systemic model of a building focused on energy and the services provided by that energy. By modeling energy conversion, we were able to establish a model based on relevant indicators, to pinpoint active energy efficiency solutions, and to implement an optimal control strategy.

Definitions of energy, energy performance and the performance indicator

Energy:

The programme uses the definition of energy as the final energy measured at the commercial point of transfer, added to the consumption of domestically-produced renewable energy. The definition covers all energy usage at the location in question.

Although it is measured in kWH, it can be expressed in other ways, by averaging weighting coefficients, to express ideas other than simple energy consumption, such as:

In euros, showing the impact of energy consumption on the building's operating costs;

In CO_2 emissions, showing the impact of energy consumption on the production of greenhouse gases that cause global warming;

In terms of primary energy, allowing consumption to be matched against production by incorporating a weighting of secondary energy/primary energy, in order to achieve national energy balances.

The energy usage optimum can vary according to the chosen measurement unit. The present results have been reached by a final energy optimization strategy

Energy performance

Energy is consumed in a building or at a location to provide a number of services. It is impossible to discuss energy performance, efficiency and economy without discussing the impact on these services, which have been grouped into three categories:

Physical comfort: temperature, light, noise, air quality and accessibility.

Psychological comfort: protection, security, aesthetics, ergonomics,…

Activity efficiency: availability, flexibility, communication, productivity of human and mechanical activities, connectivity with external networks.

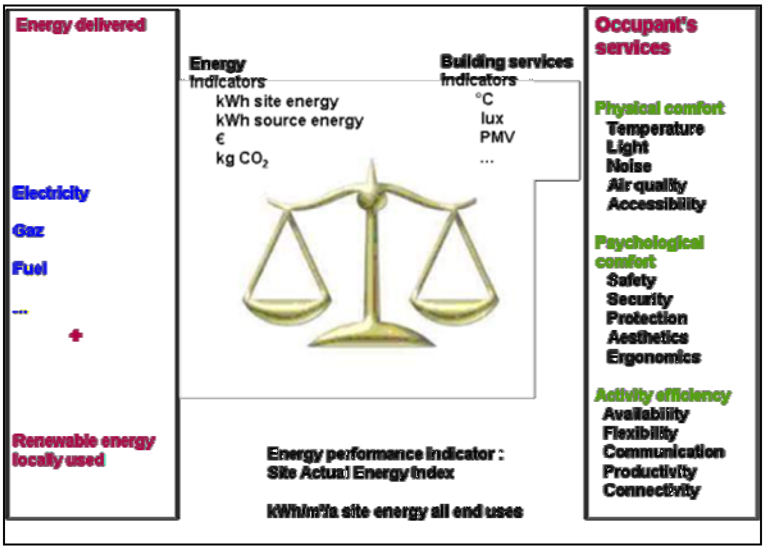


Fig 2- a definition of energy performance in a building

Energy performance is the measure of the correlation between energy consumption and the quality/quantity of services provided. A numerical indicator of this performance can be produced using a ratio showing the effective energy consumption over a given period and a value representing the services provided by the energy. Examples include the number of meals in a restaurant, the number of room nights in a hotel or the energy consumption of servers in a data center. In buildings where the predominant activity is human (residential, service sector) the best measurement of the quality of physical and psychological comfort is the area occupied in m². If the occupancy level is unknown or considered average for the sector, its variance is ignored. Area in m² is measured differently depending on customs in different countries or sector of activity, on ease of access to information, or on the objective that is assigned to the measurement. The most commonly used measurement is gross floor area, defined as the area within the external face of the walls and covered by a roof.

The numerical indicator of a building's energy performance is the site actual energy index (SAEI) representing total annual consumption of final energy all end uses expressed in kWh and scaled to the surface area of the building.

Energy efficiency

This measures, in percentage terms, an improvement of the energy performance against a reference point achieved by optimizing the services provided by energy consumption. It complements the notion of energy sobriety, the objective of which is a reduction in the level of demand or the number of services provided by the energy.

Systemic approach to energy in a building:

Between the final energy (the energy supplied to a site) and the services provided by this energy, there are two subsystems, displayed in Figure 3: the distribution system and the consumption system.

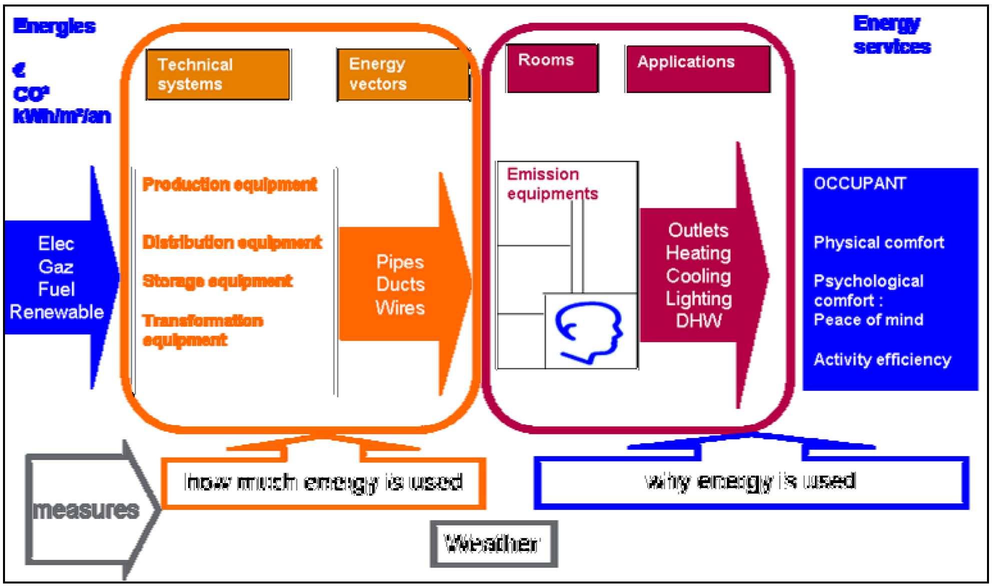


Fig 3 - the energetic system can be divided in two subsystems : distribution systems structured by vectors and consumption system structured by rooms

On one side, the distribution system transform, and condition the energy in order to distribute through three network types: wires, pipes and ducts. The two main optimization principles for this subsystem are the selection of high performance technical equipment and the dynamic management of this equipment to reduce losses. In this subsystem, meters are used to give an overall understanding of the consumption in each vector and the performances of these technical production and distribution systems, imply energy losses. This is the world of equipments.

On the other side, the consumption system structured where energy is consumed for particular uses (heating, lighting, motors, activity, plugs etc.) in each room or usage zone. In this part, the meters are used to tell us why energy is consumed, if this consumption is useful and to give us the quality of the services provided to the occupants and their activities. This is the world of people.

Finally, the external environment : external heat, light, wind and humidity influence, positively or negatively through the quality of envelope and equipments, the energy consumption necessary to create an efficient internal environment.

As a consequence the energy performance instrumentation plan involves energy meters on vectors to understand the energy consumption, comfort sensors, occupation sensors and application meters to understand services brought by this energy and sensors to measure exogenous variables as weather impact.

Three families of energy-efficiency solutions

From this analysis, we can further divide energy-efficiency solutions into three large families:

1 - Passive solutions that enable the static improvement of the Building Intrinsic Quality (BIQ) that condition the necessary energy consumption on the adaptation of the internal environment. The four characteristic dimensions of this quality are isolation, inertia, air tightness and a criterion that reflects the capacity of the building to recoup light energy and heat from the sun. Many studies have been conducted on the passive improvement of the buildings in the design phase or, more difficultly, in the renovation phase.

2 - The choice of high-performance equipment that, for similar services rendered, reduces unrecoverable energy losses. One can note, for example, heat pumps with an output greater than 1, HCP, and experiences and initiatives seeking to reuse dissipated thermal energy (recoverable energies) in grey water, on extracted air, and so on.

3 - Active solutions, (field of HOMES programme), that dynamically enable:

- The provision of information to various stakeholders of the building : the monitoring.

- The adjustment at any time of the operational modes of the equipment to provide the necessary energy to satisfy the requirement level of the services rendered to the occupants: the active control.

Active Control strategies

The systemic analysis methodology of technical and energetic systems has led us to define two control strategies to improve the energy performance of the sites the summarized in Figure 4. They are:

"First reduce the energy needs in each room by optimizing the comforts and activity conditions"

"Then optimize the energy supply in each vector to serve these needs"

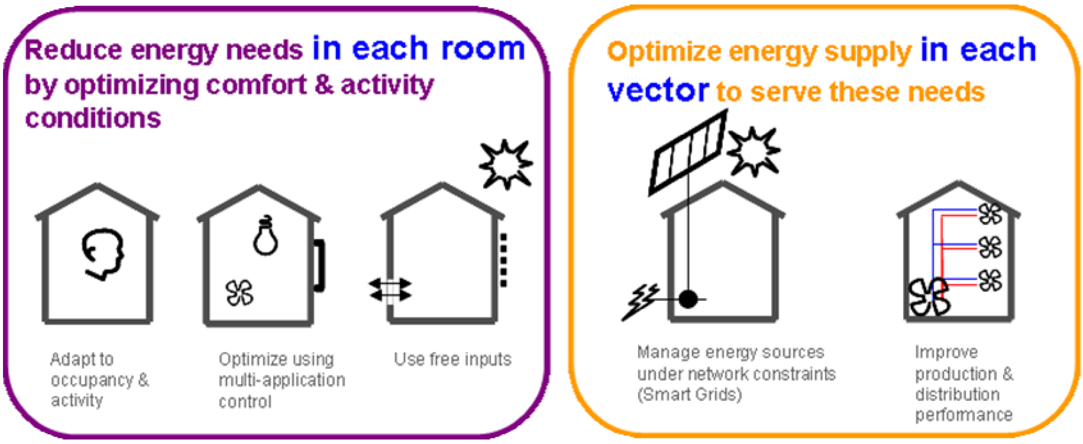


Fig 4 - Active control strategies for the energy-efficiency of buildings

Reduce the energy needs in each room

A saying is that “the cleanest energy is that which has not been consumed”. The control strategy to reduce the energy needs in each room can be broken down into four drivers:

- In the absence of an occupant and/or activity, service is no longer provided and the room is managed in order to minimize the total consumption of the site.

- When occupants are present, the demand level for services rendered, and particularly for the indoor environment quality, depends on the type of activity, the season, the number of occupants, and the ability to use external inputs (free inputs)

- The optimum consumption of a room is not the sum of the optimums of each application. A multi-application control that takes into account all the consumption components of a room or zone is more efficient than the optimization functions of heating, lighting, ventilation, or powering activities optimized separately. [3], [4]

- The building is not only smart, it is mainly obedient: On one hand, it is known that full manual control is particularly energy intensive. On the other hand a fully automated building can be energy efficient but can be anxiogenic and therefore impact negatively the human activity efficiency.

The control strategy made by the programme is to provide the occupants with the rights to define the parameters of their perceived environment when they are in a room. Automation controls unnoticed parameters, and automatically sets the energy optimization when the occupants leave.

These four drivers are applied in each room. The work has led us to define a typology of 20 different premises (including outdoor areas of the building considered by extension as a "room") and six profiles of occupation types that can describe all of the buildings and business sectors.

Optimize the energy supply in each vector to serve these needs

This control strategy drives the production and distribution equipment, according to the sum of the requirements stated by the rooms. For illustration, the exhaust temperature of a boiler is not correlated to the outdoor temperature, but to the sum of the needs of the rooms on the carrier “pipe”.

In addition, it optimizes the use of energy sources with respect to their availability, and their contribution to an optimization criterion which can be euros, GHG emission contribution, site energy, source energy, etc…. To do this, it implements forward-looking strategies or the consumption report, available storage and retrieval and contributes to bringing capacity to the smart grid, freeing consumption that has little impact on the quality of services rendered.

Architectures of the command control

These two strategies of command control are carried through their industrial development through a command control architecture (Fig 5), structured around the concept of room-control and its ecosystem: comfort and activity sensors [5], actuators of different consumptive devices including the outlets controlling mobile equipment and an HBI (Human Building Interface) allow the occupant to control their environment and see the consequences of their energy choices. At the central level of the building, controllers of energy carriers and the energy managers are the conductor of the global optimization and allow dialog with the external environment (smart grid ready)

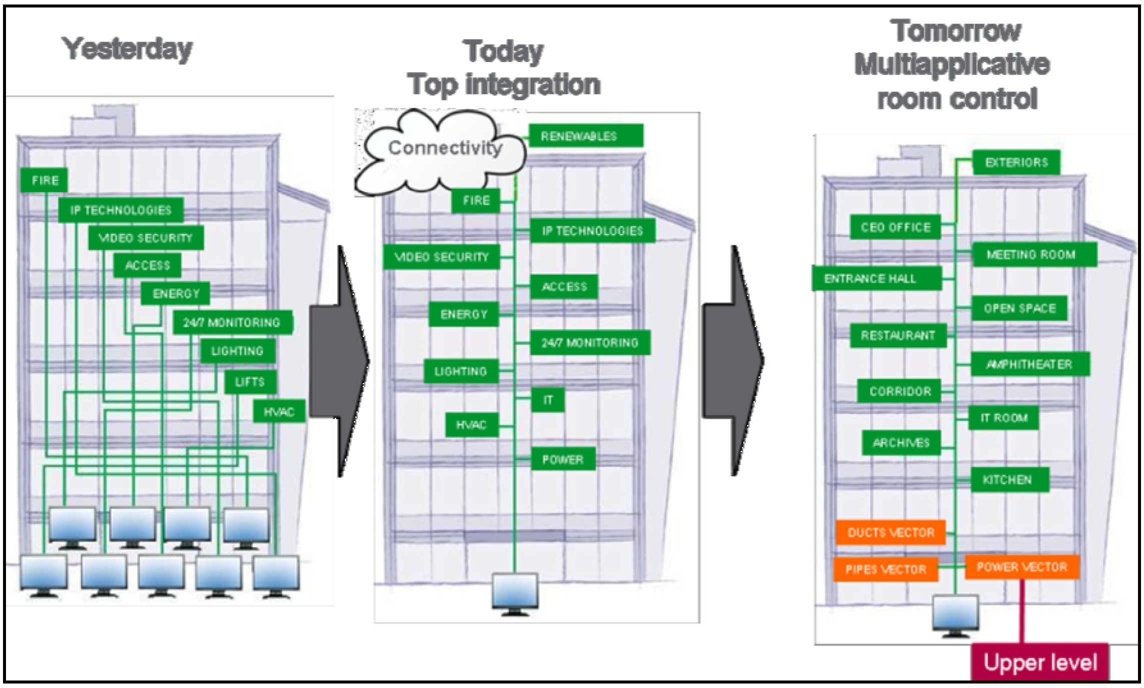


Fig 5 - Control architecture dynamic: yesterday, today, tomorrow

Assessment on HOMES pilot sites

HOMES pilot sites description

Five pilot sites were identified to enable the most comprehensive assessment as possible of the potential savings of the control strategy [6],[7]. For practical reasons, they were located in France, but their choice was guided by covering the maximum of diverse situations encountered across Europe:

Office building: This site is a part of an office building located near Chambery (mountain/continental climate). The studied zone is a floor that contains nine office rooms and a meeting room (462 m²). Heating/cooling is done by multi-split units. Single flow ventilation with relative humidity dependant outlets provides new air.

Primary school: This one-floor building (900 m²) is located near Grenoble. It includes 5 classrooms, a polyvalent space, a lunch area and a computer room. A gas boiler provides heat through various emitters (radiators, a fan coil unit and an air handling unit). There is no cooling device and very limited mechanical ventilation. The main challenges with this building are its complex geometry and a highly intermittent use.

Hotel, XIXth century building: The third pilot site building is a 2,700 m² hotel built on French Riviera in 1896 (Mediterranean climate). This is a five story high building, located downtown. The building includes a restaurant, a sauna, a meeting room and a garden with swimming pool. Heating and cooling devices include a gas boiler, a cooling rooftop unit and several reversible heat pumps. Kitchen and laundry are located in the basement.

Residential, collective: The most recent site is a social housing complex (1,500 m²), near Paris (oceanic climate) built in 2010. The building was built under French regulation RT2005 with a THPE EnR label (very high energy performance, with renewable energy production). Heating and cooling is provided by a heating floor connected to a reversible heat pump. Domestic hot water is done through a mix of a solar collector and electrical heater. There are also 200 m² of photovoltaic panels.

Hotel, modern building: The last pilot site is a 30 years old hotel built in a Mediterranean climate zone in the southwest of France. The hotel is 900 m² on two floors with only electrical energy, including electrical zone heaters. The building includes 36 guest rooms, a reception, kitchen, restaurant, and meeting room, and in 2010 was equipped with domestic hot water solar heaters.

Preparation of the models

The pilot sites were equipped with a complete set of sensors (about 90 to 100 variables measured on each site). These sensors provide energy measurement, occupancy and ambiance data. All of the data points are recorded in 10 min intervals and are transferred twice a day to a central server. We applied the definite instrumentation plan, built to measure the site actual energy index, including :

1 - Room level measurement:

• Comfort data through 4 indicators: temperature, humidity, light and CO_2, and occupancy data using a presence detector.

• Energy consumed in the room, measured for heating/cooling, domestic hot water (DHW), energy flow lost by ventilation, lighting, Other Usages of Electricity (OUE), for example, plugs and other main loads.

•2 - Energy used in energy vector systems data measurement: electricity, hot water energy for heating/cooling network, energy for DHW system,

3 - Weather station: temperature and humidity, speed and direction of wind, direct and indirect sunlight)

We created five simulation models of these pilot sites with the aim of approaching real life as closely as possible. If a perfect reproduction still remains a utopia and hence an objective, the models created are representative of the pilot sites. We used the available measures to readjust the site simulation models. By way of illustration, the measurement plan allowed us to measure accurately the effective air tightness for the primary school; this measure was used to calibrate the parameters of the simulator.

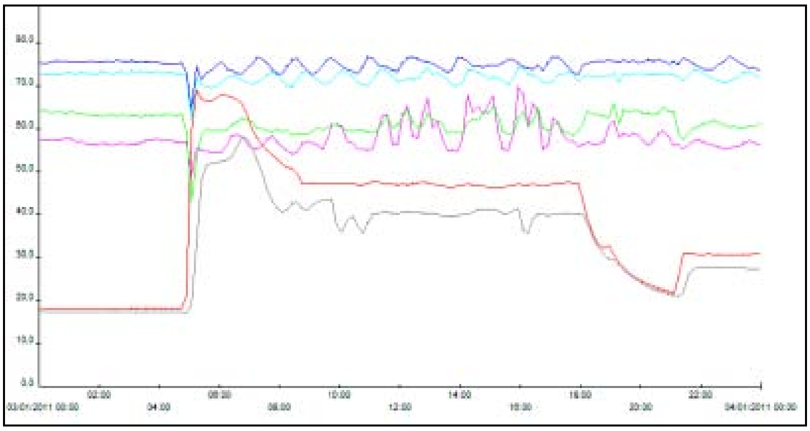


Figure 6: Monitoring example: school heating water network temperatures for a typical winter day: boiler input (green) and output (dark blue), common area air handling unit input (cyan) and output (magenta), classroom input (red) and output (gray)

Evaluation methodology

We have reproduced two reference situations with these simulation models:

Reproduce the reality of the operation, occupation of the site as closely as possible to measure the usage and consumption conditions.

Reproduce, all other things being equal (especially the envelope, the performance of equipment, weather and occupancy), the virtual implementation of the HOMES catalog control functions corresponding to the lever "reduce the energy needs in each room," acting on the equipment as they are in the real buildings, but presupposing them to be controllable on a room by room basis.

The control strategy was designed to operate at constant physical comfort; the comfort is defined, within the limits of the available comfort indicators and the capacity of the simulator, to maintain a sufficient level for three areas: temperature, light level and the rate of CO_2 considered as a tracer of air quality.

Comparison of the results

The measured results of the simulation models of the five actual sites ranged from 22% for the lowest one which was the residential community of Vaux sur Seine, to a savings of up to 56% for the primary school of Montbonnot.

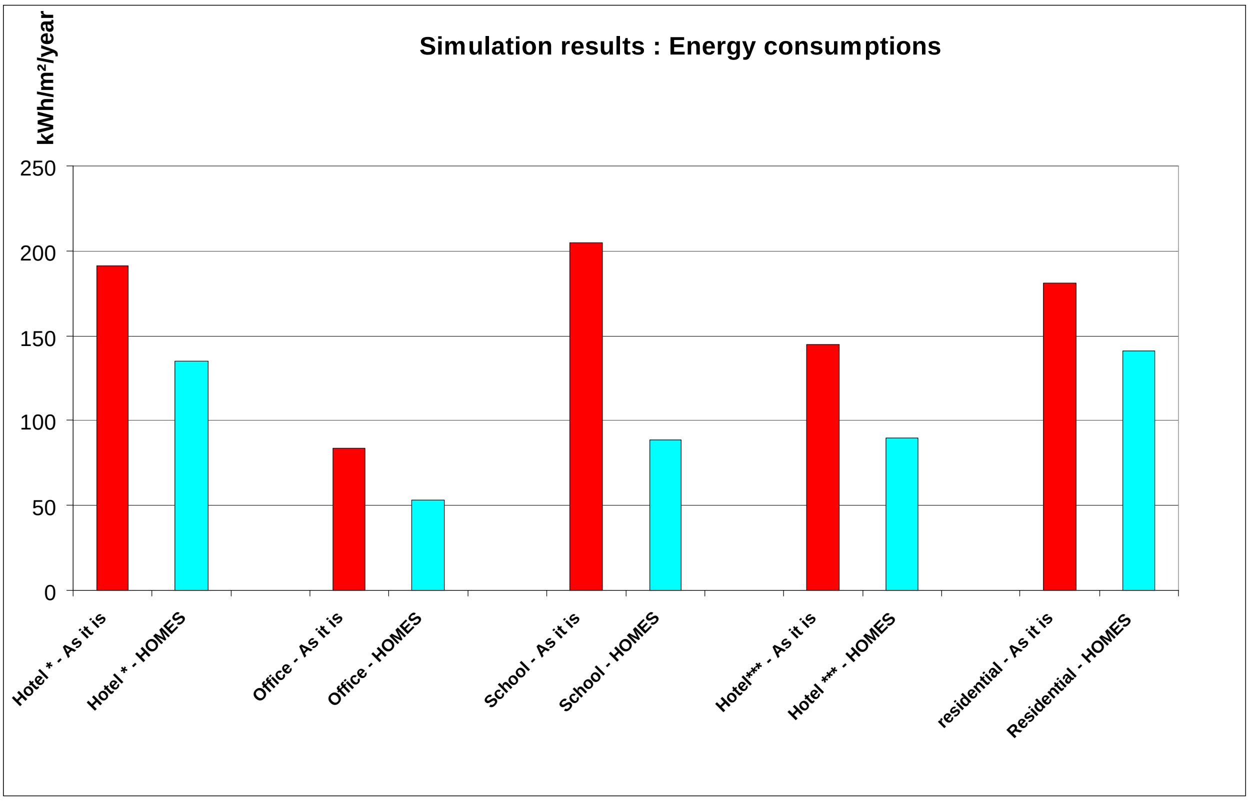


Fig 7: Simulation results of the consumption of the pilot sites

These results require further validation campaigns and can be:

- Refined by improving the quality of the "real life simulator" (for example by introducing masks both near and far, measuring the intrinsic quality of the building in isolation and inertia, improving the thoroughness of the evaluation of the comfort perceived by the occupant, etc.

- Improved by adding to the already implemented set of control functions "reduce the energy needs in the rooms," the functions of the HOMES catalog that correspond to the second strategy that is to: "Optimize the energy supply in each vector to serve these needs" that will introduce, in particular, the concepts of storage and retrieval of energy and the contribution to the electrical grid capacity market.

Conclusion

One of the other achievements of the programme has been to make a projection of the potential savings brought by the HOMES strategies of active control on European existing building stock, reconstituted statistically in a database. This database is organized by country, sectors and type of surface, and sets forth the energy consumption of Europe caused by buildings

On this basis, we have projected the potential of the estimated savings without limitation to technical or economic feasibility, which led us to the three control strategies including gains tied to monitoring to an asymptote to a 50% savings for the stock. Beyond the numbers, this analysis shows that for the stock of existing buildings in Europe, active control strategies have the same order of magnitude of potential savings, if one looks for the optimal thermal quality of their envelopes or if all the technical equipment installed were replaced by their top performing equivalents.

Of course, these potential gains are not equally distributed among all of the buildings. For example, the more intermittent the building is, the more successful active control strategies are; the more the building has ongoing occupancy, the more performing passive energy efficient strategies are; in the two cases, they are complementary. Another example is illustrated in the following figure (Fig 8) that shows the potential gain differentiated by business sectors.

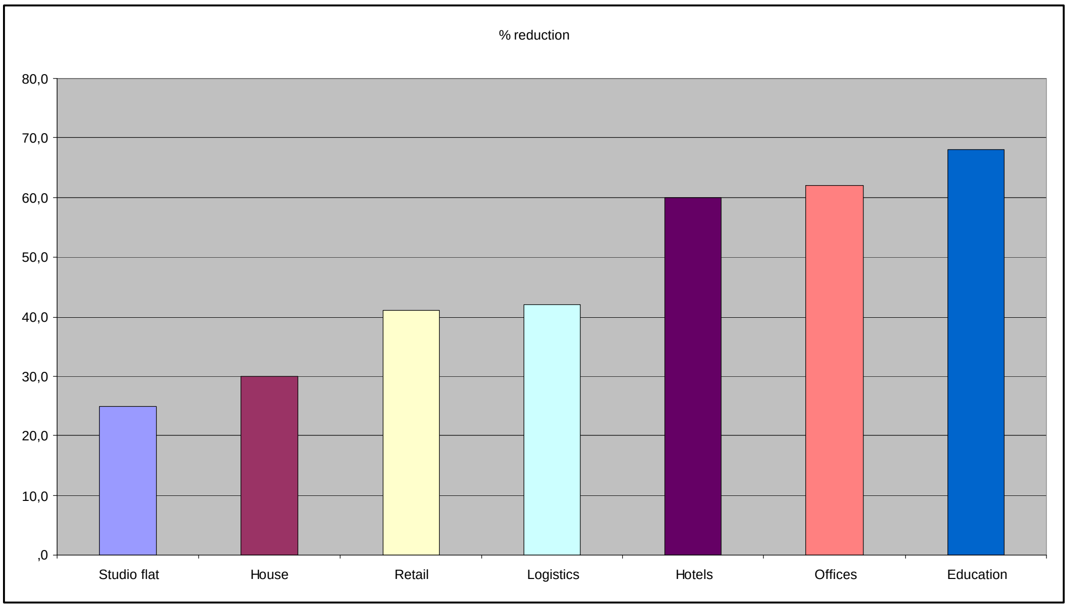


Fig 8 : Estimative saving potential by sectors in European stock

These extremely encouraging results provide new ways to reduce energy consumption of the stock and meet the environmental objectives that are established in Europe.

But they impose another way to view energy and its uses in buildings that is summarized in three concepts:

"The actual energy performance of a site (measured by the SAEI) is a different notion than the thermal performance of the building and must be approached globally, with respect to all services rendered by the energy "

"Active Energy efficiency including room based active control and stakeholder information system has the same saving potential to improve the European building stock than the Building Intrinsic Quality improvement."

"To control the energy optimization of a building, it is necessary that its technical equipment be controllable by room."

Acknowledgement

This work and attached figures are part of the HOMES collaborative programme (http://www.homesprogramme.com) funded by OSEO (http://www.oseo.fr).

References

[1] Najmeddine H., Suard F., Jay A., Marechal P., Sylvain M., Mesures de similarité pour l'aide à l'analyse des données énergétiques de bâtiments. In proceedings of the RFIA 2012 conference - RFIA 2012 (Reconnaissance des Formes et Intelligence Artificielle), France (2012).

[2] La Tosa V., Marié S., Bernier F. and Piette D., Pervasive Energy Measurements For Buildings Monitoring, in proceedings of the 2nd Workshop on eeBuildings Data Models, CIBW078 - W102, 2011.

[3] M. Y. Lamoudi, M. Alamir, and P. Béguery. Distributed constrained model predictive control based on bundle method for building energy management. In 50th IEEE Conference on Decision and Control and European Control Conference- Orlando, 2011.

[4] M. Y. Lamoudi, M. Alamir, and P. Béguery. Unified NMPC for multi-variable control in smart buildings. In IFAC 18th World Congress, Milano, Itlay, 2011.

5] M G Chabanis HOMES comfort sensor description –International Conference on Microelectronics and Nanotechnology (ICMN 2011)

[6] M. Y. Lamoudi, P. Béguery, and M. Alamir. Use of simulation for the validation of a predictive control strategy. In 12th International IBPSA Conference , Sydney, Australia, 2011.

[7] P. Béguery, M. Y. Lamoudi, O. Cottet, O. Jung, N. Couillaud, and D. Destruel. Simulation of smart buildings HOMES pilot sites. In 12th International IBPSA Conference , Sydney, Australia, 2011.

The impact of policy measures on the electricity demand of the tertiary sector of the European countries: An analysis with the bottom-up model FORECAST

Martin Jakob[2 *], Tobias Fleiter[1], Giacomo Catenazzi[2], Simon Hirzel[1], Felix Reitze[3], Felipe Toro[3]
[1] Fraunhofer Institute for Systems and Innovation Research (ISI), Karlsruhe
[2] TEP Energy GmbH, Zurich
[3] Institute for Resource Efficiency and Energy strategies (IREES GmbH), Karlsruhe

* Corresponding author: Martin Jakob, TEP Energy GmbH, Rotbuchstr. 68, CH-8037 Zürich, Switzerland, Phone: +41 43 500 71 71, Fax: +41 43 500 71 79, Martin.Jakob@tep-energy.ch

Abstract
The paper assesses different scenarios which are characterized by different levels of policy measures and programmes regarding the future electricity demand of the tertiary sector in Europe using a detailed bottom-up model. The model is designed and being developed by the authors and is implemented to forecast the electricity demand for different scenarios up to 2035 with an outlook to 2050. The model, called FORECAST, differentiates between 29 countries, and disaggregated by 8 sub-sectors and fifteen building and user related end-uses such as lighting in buildings, street lighting, electric heating, ventilation and cooling, refrigeration, cooking, laundry and data centres with servers.

The model adopts a bottom-up methodology which consists of basic drivers such as number of employees or floor area, specific energy service drivers such as equipment or diffusion rates (e.g. share of cooled floor area, no. of computers per employee) and specific energy consumption indicators. The latter consist of technical information on the end-uses such as installed power, energy demand per unit of driver, and utilisation rates such as full load hours. Diffusion rates are determined by relating appliance and building technology stock data to (mostly) physical drivers. Data stem from norms and standards of electricity consumption in commercial buildings, market and potential studies, end-use specific studies, particularly from preparatory studies of the EU Directive on eco-design of energy using products. Official statistical sources from Eurostat and country energy balances are used to calibrate the model.

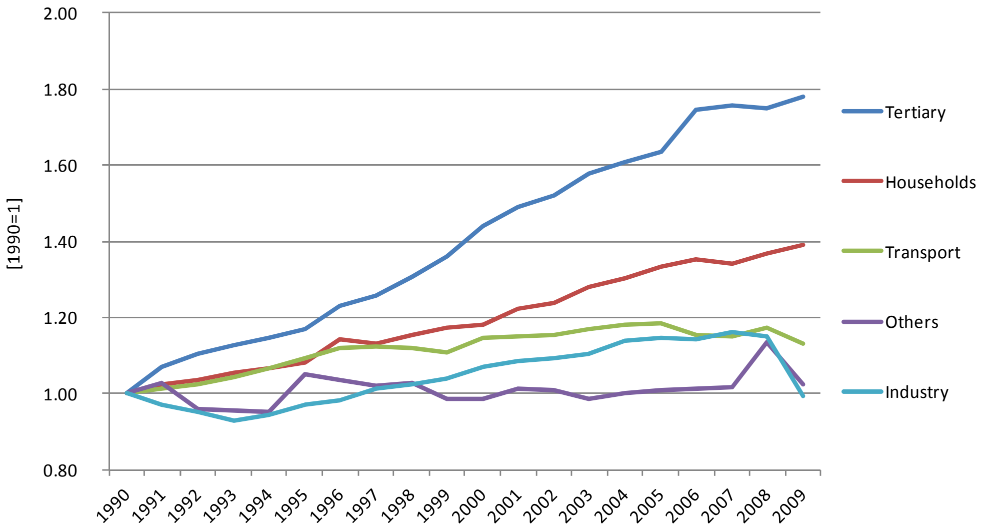
The impact of a bundle of policy measures is estimated by a comparative analysis of different scenarios. Scenarios entail different the diffusion rates and different saturation levels.
Energy-efficiency measures aim at reducing both installed power and utilization rates and cover technologies and practices such as efficient lighting, ventilation, air-conditioning, refrigerator and freezing systems, pumps, chillers, and appliances such ICT devices, dryers, substitution technologies such as heat pumps, organisational and operational measures such as control systems (e.g. occupancy and daylight controls), facility management and building energy management systems.

Results show an increase of the electricity demand of the tertiary sector by twenty to thirty percent up to 2035 in the reference scenario. Demand increase is attenuated or even completely compensated in the case of other scenarios, depending on the amount and the intensity of underlined policy measures.

Introduction

Between 1990 and 2009 electricity demand of the tertiary sector in the EU27 has been increasing by almost 78 % and reached about 770 TWh in 2009. As compared to the other sectors the tertiary sector shows the most dynamic development over the past fifteen to twenty years (Figure 1). As it is expected that electricity demand of the tertiary sector will continue to be increasing in the future policy measures to curb demand are becoming more and more relevant for this sector.

Figure 1: Development of electricity demand by sector in the EU27 as an index (1990=1)



Source: Eurostat

Thus, knowledge about the potential impact of energy-efficiency policy measures to mitigate electricity demand of the tertiary sector is crucial. The potential impact of such measures in absolute terms depends both on the specific potentials, on the relative significance of the end uses (energy services) they refer to in each sector, and on their diffusion within each sector. However detailed statistical information about electricity demand which would be an important foundation to estimate these impacts is scarce. On a European level it is only available for the tertiary sector as a whole and only a few studies have assessed the shares of different end-uses; these show differing results together with a high degree of uncertainty [1, 2, 3, 4]. Studies on a national level are often not comparable due to different definitions and system boundaries [5, 6].

For this reason Fleiter, Hirzel, Jakob et al. (2010) [7] presented a static bottom-up calculation approach to model the demand tertiary sector in Europe for 29 countries (EU27, Norway and Switzerland) for the year 2007. The approach was differentiating by 8 sub-sectors and 13 (mostly building-related) end-uses including lighting, electric heating, ventilation and cooling, refrigeration, cooking, data centres with servers and others. As concluded by [7] this approach is able to explain quite well the electricity demand of the tertiary sector in Europe. The 7 most relevant countries in terms of their estimated total electricity demand of the tertiary sector - France, Germany, Italy, the Netherlands, Poland, Spain, UK - are within a range of +-10 % as compared to Eurostat statistics. These results therefore provide a good data basis for bottom-up modelling of the future electricity demand of the tertiary sector. Furthermore, these detailed bottom-up estimations can be used as a basis for designing energy efficiency policies and provide a sound starting point for ex-ante and ex-post estimations of their impacts. As such they also form the foundation for a bottom-up model which is being developed by the authors to forecast the electricity demand of the tertiary sector up to 2035.

To determine the impact of novel technologies and other energy-efficiency measures (e.g. organizational measures) as elements of effective energy efficiency policies the static approach as presented [7] was extended from one year to a period of several decades, hence to develop a detailed bottom-up simulation model. Thus the present study aims to calculate and assess the impact of electricity-efficiency policy measures targeting the tertiary sector in Europe for 29 countries (EU27, Norway and Switzerland) by comparing two scenarios. The model is disaggregated by 8 sub-sectors and 13 (mostly building-related) end-uses including lighting, electric heating, ventilation and cooling, refrigeration, cooking, data centres with servers and others.

Methodology

We adopt a bottom-up methodology which consists of a “sum product” of global drivers such as the number of employees or floor area, specific energy service drivers (specific equipment or diffusion rates, e.g. share of cooled floor area, number of computers per employee) and specific energy consumption indicators. The latter consist of technical data on the end-uses such as installed power per unit of driver.

Sector definition

The tertiary sector, also referred to as the service or commercial sector, covers all the economic sectors not part of the primary economic sector (agriculture, forestry, fishery etc.) or the secondary economic sector (industry). Hence, the tertiary sector comprises the NACE sub-sectors G to S (NACE rev. 2.0). We differentiate between Trade (G), Hotel and restaurant (I), Traffic and data transmission (H, J), Finance (K), Health (Q), Education (P), Public administration (O), Other services (L,M,N,R,S), see Table 1 in [7]. Electricity demand of the tertiary sector includes both, building-related energy use of these sub-sectors and other energy use such as street lighting, ventilation of tunnels, public transport infrastructure and others. An exception is the sub-sector “Traffic and data transmission,” where the transportation energy for trains, subways, trams etc. is – as is usual in energy economic analysis – not accounted for in the tertiary sector, but in the transportation sector.

Calculation approach

Electricity demand of a given year is determined as the product of the specific energy demand per unit of driver (e.g. number of computers, floor area cooled / ventilated, etc.) multiplied by the quantity of the given driver. The driver is further decomposed down into an energy service driver *D* (e.g. computers per employee, share of floor area ventilated/cooled, etc.) and a global driver *G* (e.g. floor area or employees). The specific electricity demand is calculated as the product of installed (full load) power *P* and the annual utilisation rate *U* (annual full load hour equivalent). A schematic representation of the model structure is given in Figure 2. As is usually the case in bottom-up simulation models its dynamics is driven by time dependent input variables. In the case of FORECAST Tertiary, dynamics is implemented by three sets of variables:

1. The dynamics of the global quantity structure *G* depends on general economic structural changes (number of employees by sub-sector) and on specific indicators (e.g. floor area per employee).

2. The dynamics of the energy service drivers *D* such as the diffusion of cooled floor area is modeled by diffusion curves whose parameters depend on the past development, the sector and the energy service considered.

3. Specific energy demand varies over time due to the diffusion of new technologies and/or energy saving options The dynamics of the specific energy demand is modeled by constant initial starting values from which the relative impact of energy-efficiency options Δ are subtracted. Energy-efficiency options diffuse into the building stock and the economic sub-sectors according to specific diffusion rates *DR*.

Thus, the modelling approach is formally described by the following equation:

$$T_t = \sum_{C=1}^{n} \sum_{S=1}^{l} \sum_{E=1}^{k} G_{C,S,t} \cdot D_{C,S,E,t} \cdot P_{C,S,E} \cdot U_{C,S,E} \cdot \prod_{SO=1}^{x} (1 - DR_{C,S,E,SO,t} \cdot \Delta_{C,S,E,SO})$$

With

T	=	total bottom-up electricity demand of the tertiary sector [kWh]
$G_{C,S}$	=	global driver [# of employee, m^2]
$D_{C,S,E}$	=	energy service driver [unit depends on energy service]
$U_{C,S,E}$	=	utilisation rate (annual full load hours) [h/a]
$P_{C,S,E}$	=	installed power per unit of driver [W/unit of driver]

$\Delta_{C,S,E,SO}$ = relative saving of energy-efficiency option EEO [%]
$DR_{c,S,E,SO,t}$ = Diffusion rate [% of energy service driver]
Indices:
C = country, n = 29
S = sub-sector, l = 8
E = energy service, k = 13
SO = number of saving options, x=1 to 3

Energy service driver & technology data
Several energy services are defined for each of the sub-sectors representing distinct appliances as well as building-related and other technologies. Most energy service drivers are related to both a global driver G and energy service driver D, some of them, (such as street lighting or cooking), are only related to an energy service driver D (see Table 2 in [7] for all the energy services considered in the model). These energy drivers represent a diffusion curve, penetration or ownership rate of the respective technology in each of the sub-sectors and each country. Energy service drivers vary over time, depending by the type of energy service driver and/or by country.

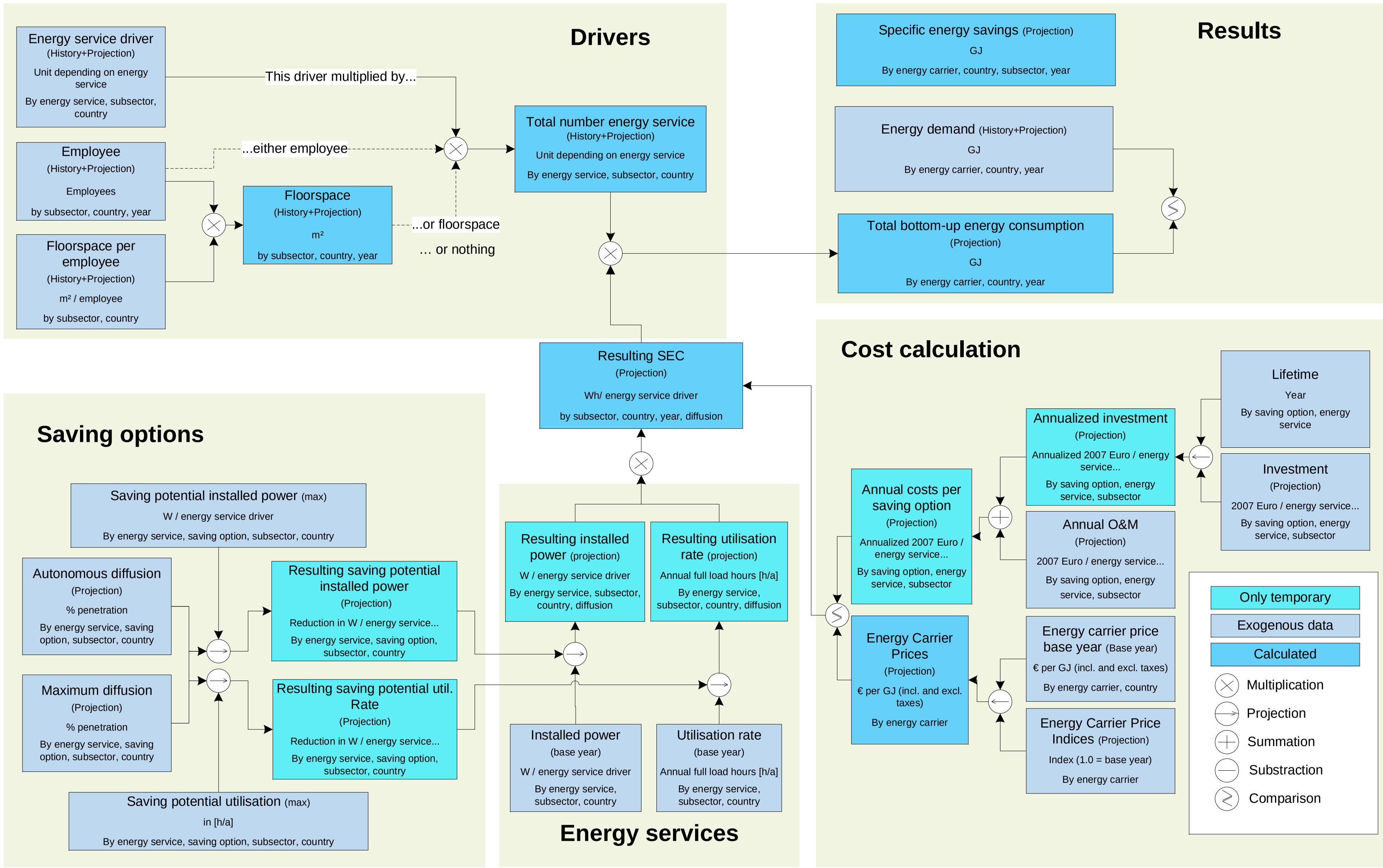
Typical examples of energy service drivers (D) are for example the share of ventilated floor area and/or with space cooling, the number and type of information and communication (ICT) devices per employee (e.g. personal computers) and others (see Fleiter et al. 2010 for details). Each energy service in each sector is characterized by a specific energy demand. These specific demand values are the product of the installed power P of a technology and its utilisation in full-load hours per year, U. These values are explicitly differentiated between sub-sectors, countries and, whenever possible, implicitly between new and existing buildings and between already installed systems and those that are retrofitted. Based on the calculation scheme, the total bottom-up energy demand for the tertiary sector T can be calculated and differentiated by either sub-sector or energy service.

Scenario definition
We apply scenario analysis and calculate alternative future developments for the electricity demand of the tertiary sector. The scenarios entail the same development for the activity related drivers like the number of employees, the floor area or the energy-service related drivers like the number of computers per employee. The only parameter changed across scenarios is the diffusion rate of energy efficiency measures. An increased diffusion implies a higher saving potential and results in lower electricity demand. Consequently, the scenarios allow concluding on the electricity saving potential available to policies that aim to accelerate the diffusion of energy-efficiency measures. We calculate the following scenarios:

- **Frozen efficiency:** the diffusion of energy-efficiency measures remains constant and thus also the SEC remains on the base year level. This scenario is calculated for purposes of comparison and shows the development of electricity demand if only the scenario drivers change.
- **Autonomous diffusion:** The autonomous diffusion is an exogenous parameter. It describes a diffusion path in case no policies would accelerate the diffusion. The autonomous diffusion further captures the effect that, due to manifold barriers, even cost-effective energy-efficiency measures are often not adopted by firms. However, the autonomous diffusion scenario represents a minimum level also in case the measure is not cost-effective. This assumption shall cover the enormous heterogeneity in the tertiary sector and the fact that the turnover of capital stock mostly implies a certain energy-efficiency progress.
- **Cost-effective diffusion:** This scenario assumes that only cost-effective energy-efficiency measures diffuse through the capital stock. Of all scenarios considered this scenario represents most closely energy-efficiency policy according to the EuP and EPBD approach. Note that we assess cost-effectiveness on the basis of a classical investment calculation using a discount rate of 35%, whichimplicitly includes remaining barriers and risk awareness of investors and end users.

Technical diffusion: the technical diffusion is exogenous input to the model and does not consider restrictions on the cost-effectiveness of the energy-efficiency measures and even expensive measures diffuse through the capital stock. Still, also the technical diffusion does not imply an "unrealistic" development. We assume that the regular turnover rate of capital stock is not affected, which implies a rather slow diffusion for energy-efficiency measures that are introduced by the replacement of long-living technologies.

Figure 2: Schematic representation of the calculation structure



The relation of diffusion paths and related energy-saving potentials are shown in Figure 3. The changes in the diffusion paths across scenarios result in different types of energy saving potentials (ceteris paribus). For policy makers particularly interesting is the no-regret potential, which implies the adoption of cost-effective measures that would due to different barriers not be adopted without suitable programs and policies.

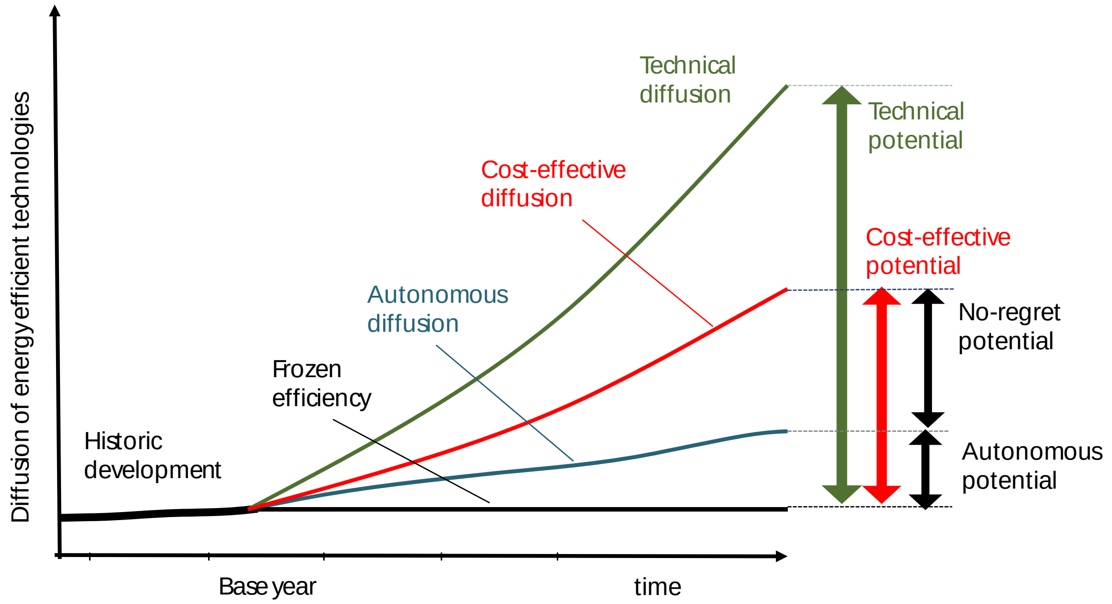


Figure 3: Definition of technology diffusion paths and energy saving potentials

Description of the data

Projection of global drivers: number of employees and floor area
As outlined above, most of the energy services are linked to a physical driver G. In most cases this is either the number of employees or the floor area differentiated by sub-sector. All these drivers are derived from exogenous sources (e.g. past trends and macro-economic forecasts) and are specific to some of the sub-sectors (e.g. number of guests in the hotel sector).

The number of employees is taken from the past employment figures by sub-sectors and countries (1990 to 2009) contained in the Eurostat database (see Table 1). The quality and completeness of this data set differs considerably between countries. Missing data of 2009 was estimated based on figures of previous years. Floor area is calculated by the number of employees and the indicator floor area per employee. on indicators derived from the Odyssee database: is the case for the countries Denmark, France, Germany, Sweden, UK, and Norway. The indicators are differentiated between countries and between most sub-sectors. For the sub-sectors public administration, traffic and data transmission and other services, they are assumed to be the same. Where data was not available for the start year of the model (2009), it was derived from past trends. The occupied floor area per employee changes over time varies, differently by country. The indicators are based on [8] and on own assumptions. Some other drivers are specific to some of the sectors (e.g. number of guests in the hotel sector).

Table 1: Employees and floor area per sub-sector in the EU27+2

	Education	Finance	Health	Hotels, cafes, restaurants	Other services	Public offices	Traffic and data trans-mission	Wholesale and retail trade	Total
Employees 2000 [1000]	13,822	6,420	18,278	7,651	24,879	14,749	12,836	29,800	128,434
Employees 2007 [1000]	15,596	6,835	21,841	9,433	32,396	15,856	13,725	32,448	148,129
Employees 2020 [1000]	17,831	7,411	26,793	10,839	41,538	16,966	15,010	35,102	171,489
Employees 2035 [1000]	18,006	7,719	28,394	10,900	45,840	16,407	15,702	35,167	178,136
Floor area 2000 [1000 m^2]	904,110	156,326	424,641	332,161	946,479	629,039	473,024	1525,533	5391,313
Floor area 2007 [1000 m^2]	982,630	165,243	516,410	401,538	1211,363	592,506	500,848	1649,416	6019,955
Floor area 2020 [1000 m^2]	1151,552	191,508	673,840	482,660	1664,436	661,690	588,686	1869,836	7284,209
Floor area 2035 [1000 m^2]	1249,813	226,575	817,290	530,020	2053,055	706,546	697,525	2033,993	8314,817

Source: Eurostat, Odyssee, own calculations

Description of energy-efficiency measures and their diffusion by type of energy service

As mentioned above, we explicitly consider 13 energy services for the bottom-up calculation of electricity demand per sub-sector and country. For the calculation of future electricity demand scenarios, we further define energy-efficiency measures (EEM) related to each of the energy services. By diffusing through the capital stock, EEM reduce the specific energy demand. For each EEM specific costs specific saving potential as well as four diffusion paths for (1) Frozen efficiency, (2) Autonomous, (3) Cost-effective, and (4) Technical diffusion respectively are specified. Both the diffusion dynamics at which energy services and energy-efficiency measures are implemented as such to take into account retrofit and replacement rates of building-energy technologies.

In the current model implementation energy services are differentiated by sub-sector based on the following rationale:

- More ventilation and cooling in some sub-sectors (internal heat loads, comfort requirements).
- More lighting in some sub-sectors (less daylight use, enhanced lighting requirements).
- More cooking, hot water, laundry in hotels, restaurants and health sector

Moreover, energy service drivers (e.g. ownership rate of equipment, share of cooled floor area) are differentiated by country (climate, economics):

- Ventilation and cooling: cooling degree days (see Jakob et al. 2008)
- Electric heating: heating degree days, history of countries
- Heat pumps: almost 0 today, more in the future
- Lighting: slightly more in the north
- Data centres: more servers per employee in wealthy countries.

Energy-efficiency measures (EEM) are either defined as a concrete technical option or as a more abstract group of energy-efficiency options. In the latter case, two different groups of saving options are defined:

- Minimum energy performance standards (MEPS): MEPS are regulatory measures that stipulate minimum efficiency levels or maximum energy-use levels acceptable for products sold (e.g. limit values of the Swiss recommendation SIA 380/4 2006)
- Advanced energy performance standards (AEPS): AEPS are more ambitious but technically feasible and refer to EEO that usually are still relatively cost-effective (e.g. target values, SIA 380/4 2006)

Energy-efficiency measures, technologies and options are specific on energy services (and hence on sectors). Typical examples are (see next sections for more details):

- Lighting: decrease of installed power, decrease of full load hour (by using occupancy and daylight-based controls)

- Air movement (ventilation systems): decrease of installed ventilation rates per m2, decrease of pressure drop, adjustment of operating hours (schedule) and capacity factors, using variable speed drives and more efficient ventilator motors
- Space cooling: more efficient chillers, occupancy, comfort and outdoor related adjustment of indoor and system temperature (gliding controls), free cooling
- Refrigeration (product cooling and deep frying):
- Space heating (heat pumps): more efficient and more heat pumps in climate mitigation scenarios
- Washing and drying: use of low temperature (cold) washing agents, use of heat pump dryers.

The technical data needed are specific energy demand per sector and per energy service. Such data is needed for the reference technology in the base year (e.g. 2009) and for energy-efficiency measures, technologies, or options. Model input data is synthesized from official statistical sources (e.g. Eurostat), studies (e.g. EuP), surveys, other models (e.g. Aebischer and Catenazzi 2007), codes and standards or technical recommendations (e.g. SIA 380/4).

In the following, we exemplary describe the underlying data for the following three energy services: lighting, refrigeration and data centres and their related EEM.

Lighting

In the case of lighting, three different sets of EEM are implemented in the model:

- The first set includes mostly more efficient illuminates (lamps) and ballasts (if applicable) that are already available on the market
- The second set of EEM consists of better luminaries on the one hand side and daylight and occupancy controls on the other hand side, reducing installed power and full load hours respectively.
- The third set of EEM focuses on new lighting technologies, particularly LEDs.

The first set of energy-efficiency options includes technical efficiency improvements in terms of installed power such as more efficacious lamps and more efficient ballasts. Concrete efficiency options and their effectiveness depends on room types, user need and thus on the sector considered. In many sectors and building categories, particularly offices, schools, hospitals, fluorescent lamps (FL) with conventional (magnetic) ballasts were installed in the 1990s und in the early 2000s as a standard lighting in many countries and are still in operation to a large extent. Although this type of lighting is already relatively energy-efficient, it still may be improved by more efficient FL and ballasts in other sub-sectors or parts thereof incandescent bulbs or conventional low or high voltage halogen spot lamps may be replaced by IRC-halogen lamps, compact fluorescent lamps (CFL) or metal halide lamps. Due to the differences of the reference efficiency and due to different EEM across sectors, energy-efficiency gains vary quite considerably (between about 16% in most sectors, 24% in the health sector, 37% in the Hotel and restaurant sector and 52% in the trade sector).

Energy efficiency measures of set 2 entail more in-depth measures and are more costly, but they also enable larger efficiency improvements. EEM are classified in two categories:

- EEM to decrease installed power: more adequate planning in case of new and retrofitted lighting systems including more efficient lighting concepts (e.g. more task-specific, floor lamps instead of ceiling lamps), higher-efficiency luminaries and other lighting technologies (except LEDs and other new developments with are modelled as EEO type 3)
- EEM to decrease full load hours: better overall lighting design including an increased use of daylighting technologies and occupancy controls
- These measures are characterized by a large variety and include improved lighting controls to adjust illumination to current need (use of sensor technology), turning lighting on and off, lowering illumination level according to user needs as well as monitoring the state of lighting equipment (deterioration, losses) and light management (see also IEA, 2006).

The effectiveness of the measures in terms of relative reduction of installed power and in terms of relative reduction of full load hours and their costs depend on the sub-sector (initial levels, existing lighting systems). Data stem from the literature (e.g. Jakob et al. 2006; Ott et al. 2009, ESD 2009), interviews with experts and norms and standards (e.g. the Swiss SIA 380/4, the German VDI 3807). Assumptions of EE improvements vary between 16% and 33% in terms of installed power and between 15% and 25% in terms of full load hours. Assumptions were made in a rather conservative approach; indeed, certain literature and energy-efficiency promoters postulate even greater savings. It should be noted that these savings are not diffused entirely into the buildings or sectors, but only to the extent of 40% to 70% up to 2035.

Energy-efficiency measures of set 3 summarize the development of new, more efficient lighting technologies. High saving potential for traffic signal lamps, medium potential for conventional lighting is made available if light emitting diodes (LEDs) substitute for conventional lighting. LED technology is expected to be the major contributor of lighting services and efficiency improvements after a phase of transition of five to ten years from now on (2009). LEDs are still on their way of development, but interesting offers are already available on the market. In 2009, efficacy of marketed products is about equivalent to CFLs. Against the background of some remaining development still needed, it is expected that the diffusion of LEDs into the market place will be starting significantly only after 2015 and up to 2020 (max. diffusion) or 2025 (autonomous diffusion). In meantime FL and CFL will rather be an intermediate technology for the remaining period to fully develop LEDs to real life requirements of different lighting applications (e.g. colour index, angle of radiation, max. power per piece).

Refrigeration

The assumptions on energy service drivers, specific energy demand and energy saving potentials are mainly derived from the preparatory study for the EU Energy-Using-Products Directive [9]. Information on refrigeration (appliance type, stock number, utilization hours, consumption and installed power) has been segmented into five major refrigerator types (see **Error! Reference source not found.**) and used to calculate its overall energy demand. Approximately 70% of all refrigerators in the tertiary sector are used in the wholesale and retail sector, followed by hotels, restaurants and cafes with 15% and public offices with 3.3%. The 2008 available stock data has been disaggregated on country basis and the major indicator for electricity demand calculations “refrigerators per employee” has been calculated to allow energy demand projections for the future, taking into account the development of employment as well as the development of GVA in the corresponding sectors.

The high economic status of inhabitants in the wealthy countries in Europe and the modern style of life (growing number of single households and fast food, increasing percentage of convenience food, etc.) as well in the metropolises as in the countryside of EU-29 cause a rapidly growing demand for convenience food. For example in Germany the per capita demand of frozen foods increased between 1990 and 2010 approximately 97% (without ice-cream) (Source: Deutsches Tiefkühlinstitut e.V.). The authors estimate that these developments will proceed by the same token in the new member states of EU, but only delayed a few years later, leading to a fast growing demand of process cooling in most countries of EU-29.

Several saving options for refrigeration have been identified in the tertiary sector. The identified five packages of measures include different single saving technologies, which are weighted and averaged. Each of the packages of energy saving measures manifests a lifetime of about 9 years. In the case of Ice cream freezers, for example high efficiency compressors, electronically commutated motor (ECM) fans as well as modulation of compressors and the increase of the heat exchangers’ surface can lead to substantial energy savings. Remote open vertical chilled multi deck cabinets and Plug in one door beverage cooler dispose the highest saving potentials in refrigeration. The saving option for RCV2 includes three measures (ECM evaporator fans, liquid suction heat exchanger, addition of a glass door) which, in a weighted manner, resulting in 57% saving (highest percentage) or rather resulting in 23% (lowest percentage) in the case of Plug in horizontal ice-cream freezer. These savings depend on the scenario because the diffusion rates are varied (minimum diffusion rate to maximum diffusion rate) depending from the accordingly framework requirements. The corresponding diffusion rates of the single efficiency technologies are based on the Base Case Scenario of the preparatory study for the Energy-using Products (EuP) Directive. There was no reduction of the utilization rates of the special cooling technologies as compared to cases without implementation of the saving option in the different scenarios [9].

ICT – data centres

The total electricity demand for ICT data centres is composed of the electricity demand of the ICT data centre infrastructure and the electricity demand of the servers themselves. Electricity demand of data centres is differentiated by three country groups (low density, medium density, high density) and by sub-sectors (see [7] for details). It is assumed that up to 2035 the number of employees per server is decreasing about 37% in the case of the country sub-category “high density of electronic equipment” and about 40% (country sub-category “medium density of electronic equipment”) and 36% (country sub-category “low density of electronic equipment”) respectively. Referring to modern life style (cloud computing and storage, music and film streaming, e-books, online shoping and banking, e-paper, all kinds of communication, etc.) the diffusion rates of ICT will increase in all subsectors of the service sector significantly. Taking into account the assumptions on the growing number of employee the resulting number of servers in the tertiary sector will nearly double (12,400,000) until 2035.

Several saving options for ICT data centers have been identified. The identified three packages of measures (1: “Saving options data center infrastructure”, 2: “Saving options bundle efficient servers”, 3: “Additional consumption due to operating safety”) include different single saving technologies, which are averaged and weighted. Each of the packages of energy saving measures manifests a lifetime of about 20 years (1: “Saving options data center infrastructure”) or 4 years (package of measure 2 and 3). Improvements, which are included in the “Saving options data center infra-structure” are cooling systems of buildings, efficient ventilation systems, higher room temperature, architecture of building, wiring system, UPS, etc. (without lighting). The Saving options bundle efficient servers” includes more efficient servers, CPU, storage technology, network equipment, cooling system, sleeping mode, virtualization, consolidation of serves and data, etc. At least the operation safety in the case of the option “Additional consumption due to operating safety” is ensured by two power supply packs per server, etc.

Table 2: Considered energy-efficiency measure (EEM) by type of energy service (selection)

Energy service	Nb.	Description of energy-efficiency measure	Savings installed power (%)	Savings utilisation rate (%)	Diffusion in 2035 autonomous (%)	Diffusion in 2035 technical (%)
Data centres	1	Saving options data center infrastructure	60	0	65	80
	2	Saving options bundle efficient server	28	0	70	90
	3	Additional consumption due to operating safety	-8	0	70	70
Refrigeration/ freezing	1	Remote open vertical chilled multi deck cabinets – RCV2	20	0	40	100
	2	Remote open horizontal frozen island – RHF4	7	0	40	100
	3	Plug in one door beverage cooler	13	0	40	100
	4	Plug in horizontal ice-cream freezer	7	0	40	100
	5	Spiral cold vending machine	7	0	40	100

Source:

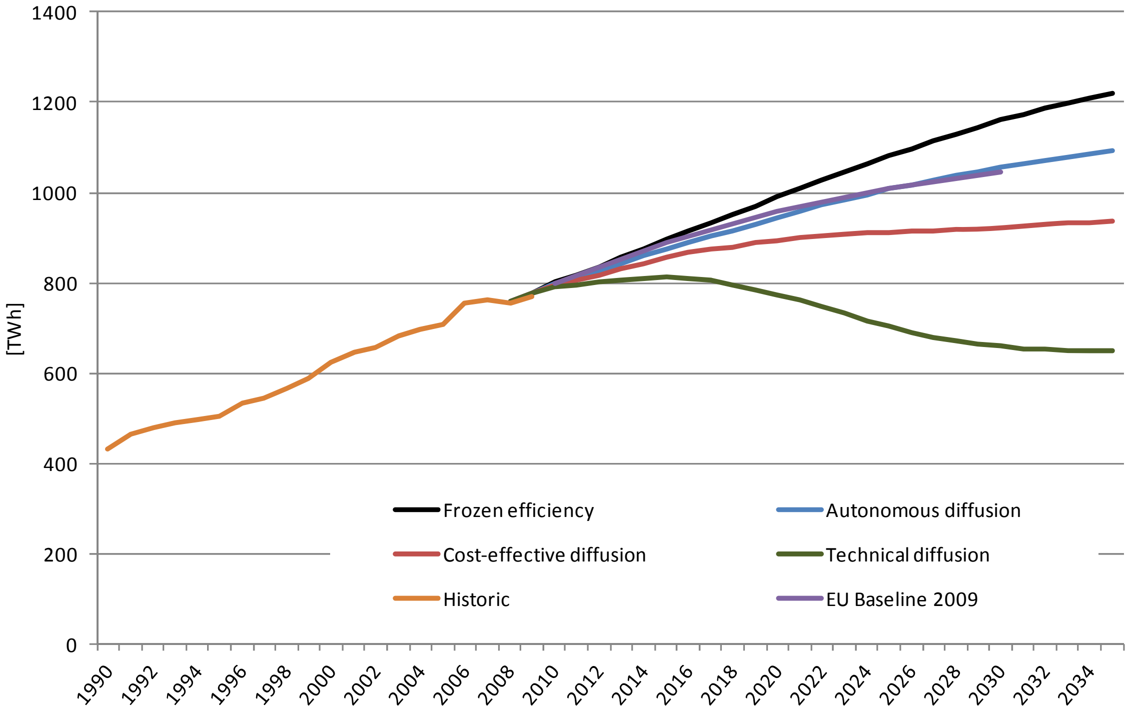
Results

The simulation results allow a break-down of electricity demand per country, sub-sector and energy-service. In the following, various dimensions are explored while the focus is put on the differences across scenarios. The scenarios vary in the diffusion speed of EEM implying different policy intensities.

The development of aggregated electricity demand in the EU27 from 1990 to 2035 is shown in Figure 4. The FORECAST projections are calibrated to the electricity demand according to Eurostat in 2008. The autonomous diffusion scenario results in a slowly saturating but continuously increasing demand. Only in the cost-effective scenario (35% assumed discount rate) demand approaches a constant development in the long term. Assuming a lower discount rate would probably result in a slightly falling electricity demand in 2035. The remaining electricity saving potentials are well illustrated by the technical scenario, which results in a demand that is only about half the demand in the frozen efficiency scenario in 2035. Even compared to 2008 a 15% reduction of electricity demand is achieved by 2035. Although, this scenario implies the adoption of EEM that are not cost-effective from a firm point of view, the underlying diffusion of EEM does not assume unrealistic replacement of capital stocks. On the other side, when long-term CO_2 mitigation targets are aimed at, even mitigation options that are not cost-effective from a firm-perspective might be less costly than other options e.g. in the electricity generation sector.

Moreover, Figure 4 includes a comparison with the most recent baseline scenario of the European Commission (labelled EU Baseline 2009 in the figure) [10].* Unfortunately the study only reports electricity demand of the tertiary and the agricultural sector as one aggregate and only for 5-year time steps, while 2005 is the most recent year with statistical data. Thus, include the EU baseline in figure 6 as index calibrated to the electricity demand in 2010 in order to make it comparable to our results. It is striking that the EU baseline demand exactly follows the path of the autonomous diffusion scenario. This is even more astonishing, as we were not able to adjust the scenario driver, the number of employees per sub-sector, to the assumptions of the EU-baseline, as these are not publically published. It should be noted that a comparison on the country level might still show deviating results. The comparison indicates that also the EU-baseline implies further (cost-effective) saving potentials. However, for a more detailed comparison of both studies, one would need to compare main economic input drivers on a country level.

Figure 4: resulting EU27 electricity demand by scenario

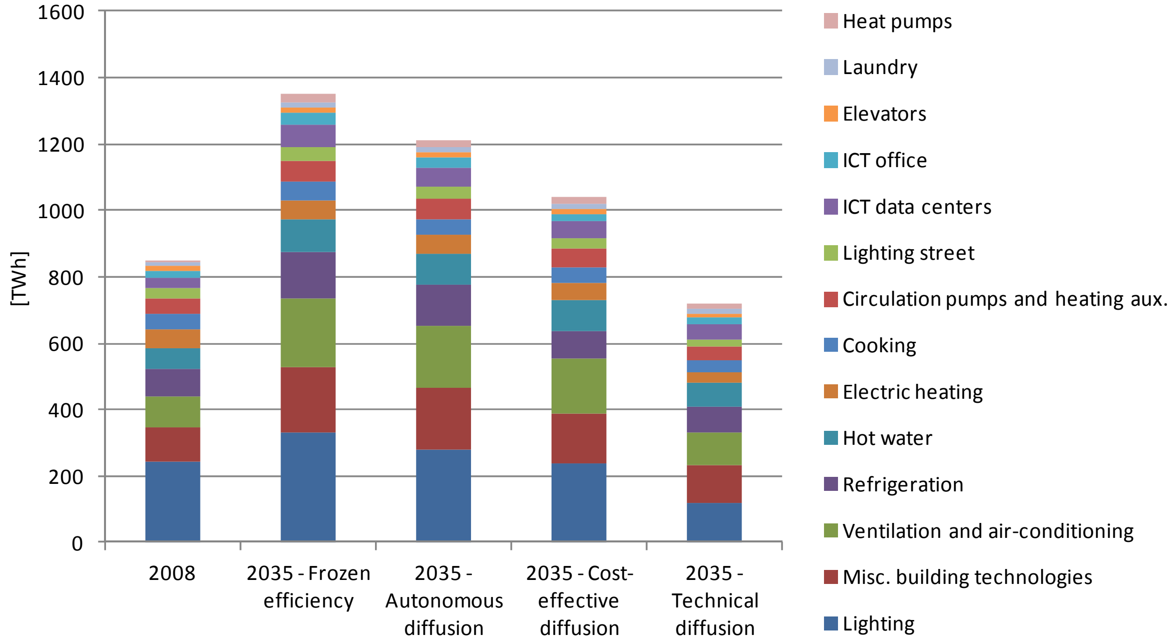


Moreover, the calculation results allow a breakdown of the tertiary sector's electricity consumption by country, energy service and sub-sector, which is shown in the following figures.

* We could not base the comparison on the recently published EU Energy Roadmap, because it does not report electricity demand on the level of the tertiary sector.

Figure 5 shows the break-down of electricity demand by energy service for all scenarios as well as for the base year 2008 for the EU27. The breakdown reveals the importance of certain energy services in 2008: Lighting (29 % of electricity demand), ventilation and cooling (11 %), refrigeration (10%) and other building technologies (12 %) account for about 62% of the total electricity demand of the tertiary sector, whereas the other ten energy services together make up the remaining 38 % of total consumption.

Figure 5: Breakdown of the electricity demand by energy service and scenario in the EU27 tertiary sector in 2008 and in 2035



The breakdown of EU27 electricity demand by sub-sector is provided in Figure 6. It clearly reveals the high electricity consumption of the wholesale and retail trade sector already in 2008 with 38 % (see Figure 6). The shares of the remaining sectors range from 3 to 14 %. The relative importance of the different sub-sectors does not vary significantly across the scenarios.

Figure 6: Electricity demand of the tertiary sector of the EU27 by sub-sector and scenario in 2008 and in 2035)

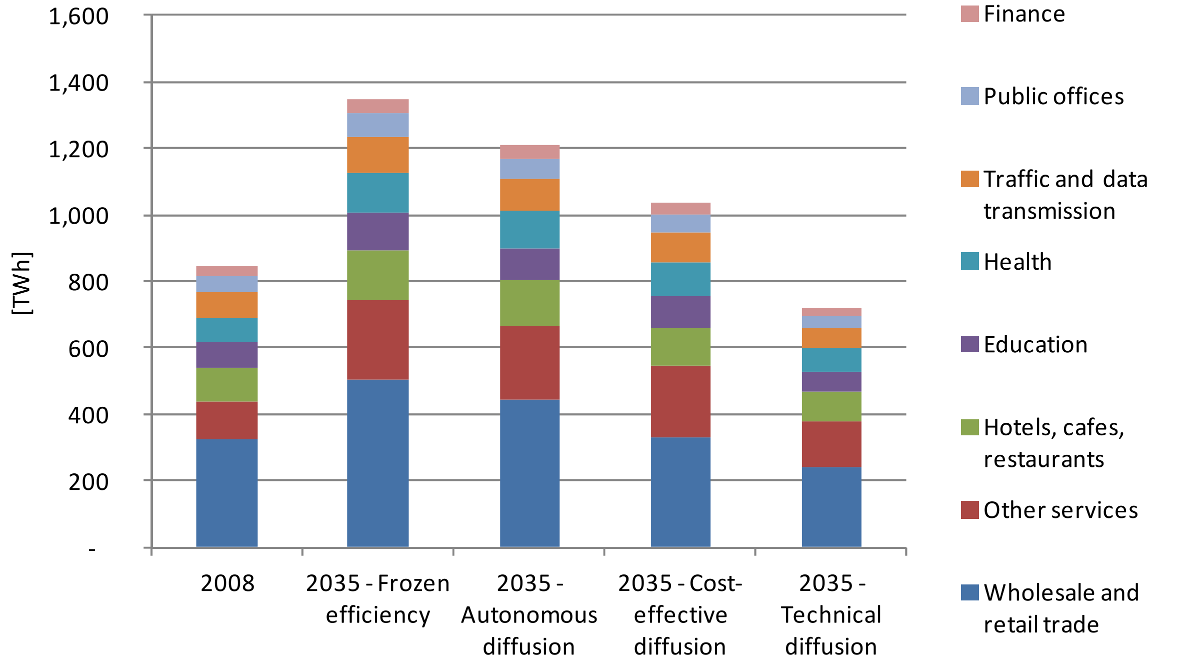
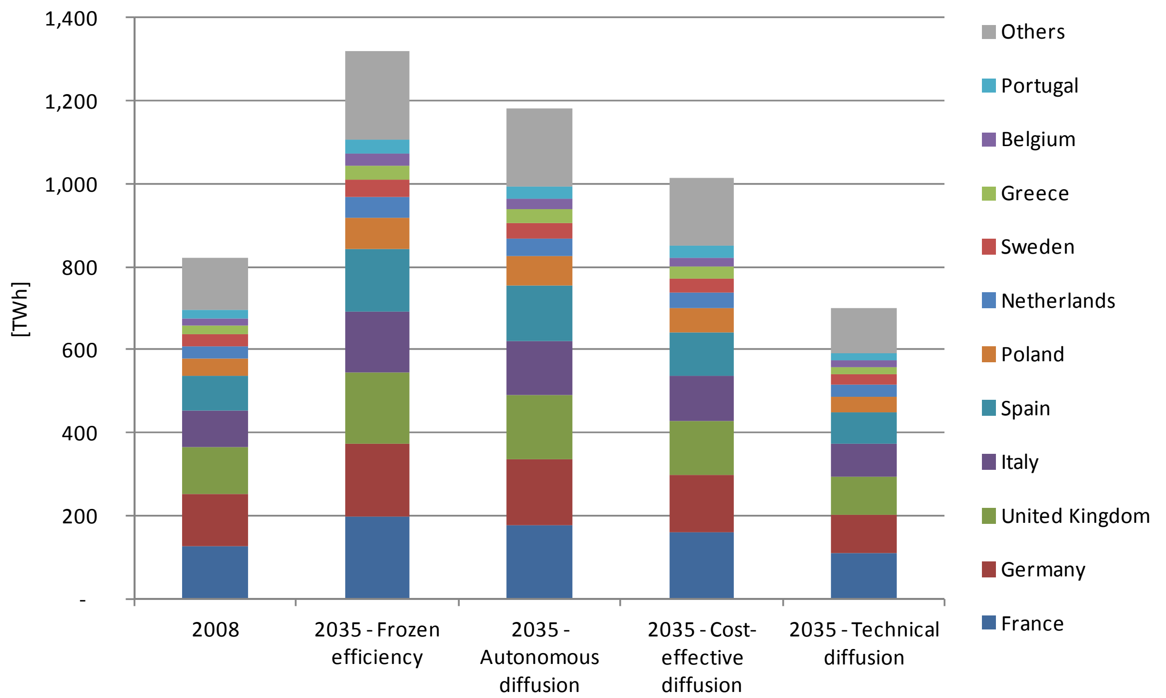


Figure 7 provides the electricity demand by country and scenario. The 7 most relevant countries in terms of electricity demand in the tertiary sector - France, Germany, Italy, the Netherlands, Poland, Spain, UK - have a total share of 74% in 2008. Until 2035 the relative importance of Germany falls slightly while Poland for example increases its share. The developments vary across countries due to varying development of employment and floor area per sub-sector, varying growth in the energy service drivers and different electricity tariffs.

Figure 7: Electricity consumption by scenario for chosen countries



Conclusions

We apply a strict bottom-up methodology to model the electricity demand of the EU27 tertiary sector on a country level up to the year 2035. The results show that the model produces consistent results also when being compared to other studies like the 2009 EU baseline scenario.

Interesting for policy questions is the fact that the model builds on assumptions about the diffusion of energy-efficiency for 13 separate energy services. These technology specific assumptions like the specific saving potential or the specific costs are mostly derived from preparatory studies for the EU Ecodesign directive, which implies a huge degree of technology realism in the scenarios.

The scenario analysis reveals that if today's diffusion speed of energy-efficiency measures is projected into the future (business as usual), electricity demand in the tertiary sector is very likely to continue to grow over the entire modelling period, although it shows an increasingly saturating tendency. Adopting all measures cost-effective for a discount rate of 35% results in a development that arrives at nearly constant development in 2035, although 23% higher than in 2008. Only when allowing for the adoption of measures that are not cost-effective electricity demand falls even 15% below its 2008 value.

Thus, the analysis shows significant potentials beyond today's business as usual. While large parts of these potentials are cost-effective, the significant demand reduction in the technical scenario also implies the adoption of costly measures. However, when comparing these measures with CO_2 abatement options e.g. from the power generation sector in the frame of an ambitious CO_2 emission reduction targets, even the options that do not appear cost-effective from a firm perspective might be cost-effective for the economy as a whole.

A comparison of the scenarios to the EU baseline scenario from 2009 reveals a close matching with the autonomous diffusion scenario (business as usual). This indicates also significantly further saving potentials entailed in the EU scenarios.

Finally, although, the analysis presented here was conducted on the EU-level, the FORECAST model also allows an analysis on the country level and further proofs promising when being applied to model the effects of policies like the EU ecodesign directive that address particular policies.

References

[1] Gruber, Edelgard; Plesser, Stefan; Dusee, Rinto; Sofronis, Ilias; Lima, Pedro; Riviere, Philippe; Rialhe, Anne (2008). El-Tertiary: Monitoring Electricity Consumption in the Tertiary Sector, D26 - report on the project results (http://www.eu.fhg.de/el-tertiary/, access: 31.01.2010)

[2] Bertoldi, Paolo; Atanasiu, Bogdan (2009). Electricity Consumption and Efficiency Trends in the European Union – Status Report 2009. European Commission Joint Research Centre (JRC), Institute for Environment and Sustainability

[3] Bertoldi, Paolo; Atanasiu, Bogdan (2006). Efficiency Trends in the Enlarged European Union – Status Report 2006. European Commission Joint Research Centre (JRC), Institute for Environment and Sustainability

[4] De Almeida, Anibal T.; Caetano, Antonio; Fong, Joao (2006). Residential and Tertiary Sectors Technologies – Role of Electricity Demand. University of Coimbra, Eurolectric

[5] Schlomann, Barbara; Gruber, Edelgard; Geiger, Bernd; Kleeberger, Heinrich; Herzog, Till; Konopka, Daria-Maria (2008). Energieverbrauch des Sektors Gewerbe, Handel, Dienstleistungen (GHD) für die Jahre 2004 bis 2006. Fraunhofer Institute for Systems and Innovation, Lehrstuhl für Energiewirtschaft und Anwendungstechnik (IfE) Technische Universität München, GfK Marketing Services GmbH & Co. KG, Karlsruhe, München, Nürnberg

[6] Abreu, Carlos; Adnot, Jeroen; Riviere, Philippe (2007). Tertiary electricity consumption in France, report for El-Tertiary: Monitoring Electricity Consumption in the Tertiary Sector.

[7] Fleiter T. Hirzel S., Jakob M., Barth J., Quandt L., Reitze F., Toro F., Wietschel M. (200810). Electricity demand in the European service sector: A detailed bottom-up estimate by sector and by end-use. Proceedings of the IEECB'10 - Fifth International Conference on Improving Energy Efficiency in Commercial Buildings, Frankfurt, April.

[8] Jochem E. (Work Package Leader), Barker T., Scrieciu S., Schade W., Helfrich N., Edenhofer O., Bauer N., Marchand S., Neuhaus J., Mima S., Criqui P., Morel J., Chateau B., Kitous A., Nabuurs G. J., Schelhaas M.J., Groen T., Riffeser L., Reitze F., Jochem E., Catenazzi G., Jakob M., Aebischer B., Kartsoni K., Eichhammer W., Held A., Ragwitz M., Reiter U., Kypreos S., Turton H. (2007): EU-Project ADAM: Adaptation and Mitigation Strategies: Supporting European Cli-mate Policy - Deliverable M1.1: Report of the Base Case Scenario for Europe and full description of the model system. Fraunhofer ISI. Karlsruhe, November.

[9] Monier, V.; Mudgal, S.; Iyama, S.; Tinetti, B. (2007): Preparatory studies for ecodesign requirements for EuPs - Lot 12: Commercial refrigerators and freezers: Bio Intelligence Service.

[10] Capros, P.; Mantzos, L.; Tasios, N.; De Vita, A.; Kouvaritakis, N. (2010): EU energy trends to 2030 - Update 2009, Luxembourg: European Union.

Expert system for identification and definition of low investive measures to reduce energy consumption and polluting emissions – EXECO2[1]

Schmidt, Michael; Arold, Jörg

University of Stuttgart, Institute for Building Energetics

Abstract

Within the framework of this project a manual which is overlapping all disciplines was developed to facilitate the discovery of low-invest energy saving potentials: the so called expert system. The structure of the expert systems is designed to reach a good user acceptance. The expert system is only effective if the user makes use of it and doesn't give up in frustration. For this reason, the idea was rejected building up the expert system as a flow chart and a check list was chosen instead. The catalogue with low-invest energy saving measures was based on experiences gained by the Institute and other bodies. Furthermore, the requirements on the energetic inspection of the EnEV (German Energy Saving Ordinance) and the directive EPBD were respected. A first test run with the operating staff of a real building showed that such test runs were given new impulses from practice which could be used to ameliorate particularly the user-friendly application. Therefore, it seems useful to examine and to further adopt the expert system in a longer testing phase.

Keywords: low-invest measures, energy efficiency, use stage, optimizing operation

1 Introduction

In Germany, the operation of buildings consumes almost 40% of the final energy consumption; the same rate applies to Europe. By 2020, the 20-20-20 objectives envisage reducing the greenhouse gas emissions by 20% and increasing both, the rate of renewables energies in Europe as well as the energy efficiency by 20%. To reach this objective, measures are necessary to reduce the energy consumption of existing buildings. All measures or legal regulations concerning new build houses and the energetic refurbishment may have only medium-term or long-term impacts, because the annual rate of new build houses and energetic refurbishment is in each case about 1%. For this reason possibilities must be found for reducing the energy consumption in short-term. One possibility is to tap saving potential in optimising operations of technical building services.

The experience from studies carried out so far [1], [2], shows that the energy consumption during the operation of buildings could be cut by 30% in short term by means of measures with low investment costs. These measures taken for improving the operation of buildings, affect the heating and ventilation systems, the domestic water heating, the cooling, the lightning and their measuring and control technology.

The aim of this research project is providing instructions for a so called expert system which allows tapping low investment-related energy saving potentials. This expert system will enable the responsible staff to become familiar with the building and their installations and to identify independently the low investment-related energy saving potentials.

[1] Research project funded by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) Reference number: SF – 10.08.18.7-09.46

The instructions contain not only technical measures, but also organizing and strategic measures. This is important because the uncovering of the energy saving potentials fails often due to organisational and strategic hurdles. The expert system shall be especially deployed in non-residential-buildings because above all the organisational measures can be transferred only to a limited extend to residential-buildings.

2 State of scientific research

The studies or the instructions carried out until now in this area have been strongly adapted for each property and limited on individual disciplines or fixed on another phase of the life cycle of a building (e.g. conception and planning) and not on the operation. The expert system worked out is a manual for identification of low investment-related energy saving potentials regarding the phase of the building operation and the different disciplines.

3 Presentation facilities of the expert system

Based on the methods of Industrial Engineering the options of presenting the expert system have been tested and selected. The organization chart and the flow chart are documentation techniques which are adequate forms. The check list is the most appropriate method for analyse. In the following, the different possibilities are described.

3.1 Possible analysis and documentation techniques

The techniques of documentation are suited for the presentation of procedures, especially of complex cycles. There are 3 types of documentation structures:

1. Written description (words)
2. Correlograms (connections between elements)
3. Process mappings (processes in logical sequences)

In practice, these 3 types are often combined.

Organization chart

The organization chart displays in hierarchical structures. A hierarchy is typically visualized as a pyramid. The guiding theme is illustrated on the 1st level. Other levels are superordinated or subordinated.

Flow chart

Contrary to the organogram, the flow chart consists of branches, combinations, dependencies and feed backs. Flow charts are suitable for the presentation of logical and temporal process sequences and the dependencies.

Check list

Check lists are used for organisation and routine problems. Well-targeted questions can initiate thinking processes and the elaborate problem-solving approaches. All different and important aspects of a problem can be presented in the check list. The look of the check lists is not specified. Each check list can be adapted for the individual application.

The check list appears for the expert system as the most suitable form. Further elaborations of the expert system refer to this form.

4 Structure of the expert system

The expert system is adaptable to buildings with different technical equipment. The partition of the system is the following:

1. Building,
2. Heating,
3. Ventilation,
4. Cooling and
5. Lightening.

For each part, respectively discipline, there are

1. check lists,
2. overview lists and
3. an annex

according to the requirements. The annex for the different disciplines is certainly combined to one document, a kind of additional booklet. The purpose and content of the different kinds of documents is described below.

4.1 Check lists

In the check lists different questions are posed and provided with instructions. These check lists are used to analyse individual subsystems such as heating circuits, HVAC systems etc. Here, the records of the actual state and the technical equipment as well as the evaluation of the operation are made.

There are different question types with various contents in the check lists. Below are some of the most used question types. If it seems appropriate to diverge from this style in individual instances, the appearance has been thus adapted. Table 1 shows an exemplar of the check lists with examples for the different question types.

Table 1: Example of the different types of questions and instructions

		Yes	**No**
CL Type 1	Are settings for the hydraulic balance possible?	☐	☐
CL Type 2	**Stairwells** a) ☐ internal b) ☐ external		
CL Type 3	Description of the ventilation zone:		
		Value	
CL Type 4	What is the heating load in the room?	kW	
Instruction 1	**Instruction:**		

Instruction 2	**Instruction for the user:**
instructions 3	**Modification recommendation**:
Instructions 4	**Organizational instruction:**

1. CL Type 1: Here, questions are posed which must be answered with yes or no. Because it was not possible to formulate all questions in the way to put only a checkmark, this type was selected. If one possible answer is marked grey (in this example the answer "Yes") there is demand for action.
2. CL Type 2: This type is used if a number of options exist. The additional number system (a) and (b) serves later for addressing. By selecting "external", later can be referred to "CL Type 2b).
3. CL Type 3: This type allows querying questions with extensive responses.
4. CL Type 4: Numerical values, real values and set points can be checked by this type.
5. Instructions 1: Explanations how the information is to interpret.
6. Instructions 2: Information intended for the user of the building.
7. Instructions 3: If the investigation shows that the equipment is not state-of-the-art, then recommendations of what should be respected by taking replacement investment are provided at this place.
8. Instructions 4: The organizational information includes measures on which the house management and the technical service can react.

4.2 Overview lists

The lists fulfil several tasks. They are used as an overview of the building and installation situation as well as a documentation of the modification. They are only be used when very many details (e.g. in case of the room by room consideration of the benefit transfer) must be investigated. Table 2 shows as an example an overview list from the part „building“ of which the parts of the building correspondent with the appropriate systems and supply circuits.

Table 2: Example for an overview list of the use in individual use zones (building)

Pos.	Use zone	Type of Utilization	Modification of the utilization?	Change in the building envelope?	Set point /Actual value $\vartheta_{Ra,Heiz}$	Set point /Actual value $\vartheta_{Ra,Kühl}$
1					°C/ °C	°C/ °C
2					°C/ °C	°C/ °C

4.3 Annex

More extensive information and instructions which may break up the text flow of the check lists appear therefore in the annex. An example for more extensive information is e.g. an instruction for the hydraulic balance. The references to the sources of third parties are also transferred into the annex. These sources include e.g. the German Energy Saving Ordinance (EnEV) [15] and different standards such as DIN EN 15251 [19] and DIN EN 13779 [20]. If something is changing in those sources, it is sufficient to modify the annex, without having to intervene in the check lists.

5 Example checklists

In the following chapter there are some examples of check lists of the expert system. Table 3 shows an example for the check list “building” and in Table 4 an example of the discipline “heating”.

Table 3: Example for a check list, here from the part „building“

			Yes	No
G_3 2.1	Has the utilization changed compared with the design-utilization?		☐	☐
	Instruction to G_3 2.1: Important changes are e.g. different times of use, a new occupancy rate (more or less employees), or changes of the internal gains (e.g. more computers or displays per person). It should be checked, if it is possible/necessary to change the operation parameter. Relevant Instructions can be found in the check lists for the installation engineering (heating, ventilation systems and coldness).			
G_3 2.2	Is this room not used?		☐	☐
	Instruction: (see Instruction H_N 2.3.8 for single-rooms) (heating, ventilation-systems, coldness)			
G_3 2.3	Is the room only unfrequented used?		☐	☐
	Instruction: If single rooms are used unfrequently see instruction for heating H_N 2.3.9.			
G_3 2.4	**Actual-Utilization**	**designed or previous utilization (should only be inscribed, if there are changes)**		
	a) ☐ single office b) ☐ group office (2-3 persons) c) ☐ open space office d) ☐ conference or seminar room e) … f) …	a) ☐ single office b) ☐ group office (2-3 persons) c) ☐ open space office d) ☐ conference or seminar room e) … f) …		

In the check list in Table 3, there are questions of utilization changes etc. handled. Possible low-invest measures in the different disciplines are listed in the chapters for the installation engineering heating, ventilation and cooling.

Table 4: Example check list for „heating limit temperature“

H_E 3.1.1	Actual value of the heating limit temperature ϑ_{HGT}	°C	
	Instruction: The heating limit temperature ϑ_{HGT} is the outdoor temperature, below which the heating system is switched on. For this, the daily mean value of the outdoor temperature should be used. You can find this settings with different names in the system control, e.g.. *Stand-By-Temperatur* (Stand-By-temperature), *Grenztemperatur* (limit-temperature), *Inbetriebnahme Temperatur* (start-up temperature), etc.		
		Yes	**No**
H_E 3.1.2	Is the heating limit temperature above the recommended **target-**	☐	☐

	value of 12–15 °C?		
	Instruction: Is the actual value above the target-value, the value should be checked and optionally adapted.		
H_E 3.1.3	Is a ventilation system connected with this heating circuit or heat generator?	☐	☐
	Instruction: In this case, the set-temperature of the air heater must be taken into account. ϑ_{HGT} should be chosen in this way that the demanded supply air temperature $\vartheta_{Zul,\ Soll}$ can be reached at any time.		
H_E 3.1.4	Is the actual value of the outdoor temperature used for the heating limit temperature?	☐	☐
	Instruction: ϑ_{HGT} should be compared with the daily mean value of the outdoor temperature, not with the actual value. If the actual value is used, it can happen that the heating system is switched on/off very often, although there is no heat-demand.		
H_E 3.1.5	Is it possible to adapt ϑ_{HGT} in summer?	☐	☐
H_E 3.1.6	Is it possible to shut of the heating system in summer?	☐	☐
	Instruction to H_E 3.1.5 and 3.1.6: If there are problems with the ϑ_{HGT} during the transition period (e.g. too low room temperatures) the heating limit temperature can increase. But it is very important in this case, that ϑ_{HGT} is reduced in summer.		
	Instruction if H_E 1.5 is "yes": Changes in the building envelope, especially concerning the insulation standard, can also influence the optimal settings of the heating limit temperature. With a better insulation you can reduce the heating limit temperature.		

Table 4 shows the questions handling the settings of the heating limit temperature. It is checked if the heating limit temperature is set correctly. If that is not the case, possible measures are shown to optimize the system operation.

6 Additional information about the resources

Both research activities and proceedings by own and third party and manufacturer's documentations, standards and guidelines are regarded. In addition, the energy saving requirements according to the German Energy Saving Ordinance EnEV and the European „Energy Performance of Building Directive"(Richtlinie 2002/91/EG) [7] with all related standards are considered. In the following, the evaluated literature will be outlined.

6.1 Standards and guidelines for inspection

In connection with the directive EPBD, various European standards that deal with the inspection of different disciplines were worked out.

These are the following standards:

1. DIN EN 15239 Inspection of ventilation systems [9]
2. DIN EN 15240 Inspection of air conditioning systems [10]
3. DIN EN 15378 Inspection of boilers and heating systems [8]

These standards contain information about:

1. Required documents
2. Frequency of inspection
3. Contents of inspection
4. Energetic Evaluation

In every standard is only a single discipline treated. The information is mostly vague and for details these standards refer to national guidelines. Concrete instructions of how to identify saving potentials for different installation types are missing.

Beside these standards, there are a few worksheets from the German Machine and Plant Engineering Association (VDMA) for the maintenance of ventilation technology, heating technology, refrigeration engineering and measuring and control technology and several worksheets dealing in more detail with refrigerating machines and plants.

1. VDMA 24186-1: 09-2002: Performance programme maintenance ventilation technology [11]
2. VDMA 24186-2: 01-2007: Performance programme maintenance heating technology [12]
3. VDMA 24186-3: 09-2002: Performance programme maintenance refrigeration engineering [13]
4. VDMA 24186-4: 09-2002: Performance programme maintenance measuring and control technology [14]

These work sheets are pure check lists for the maintenance of the installations; the building operation is not included. The measures given from VDMA data sheets are only regarded if they have influence on the energy consumption of the appropriate installation.

6.2 Research reports

In addition to the relevant standardisation, more literature will be analysed. In this field, the following research projects have been executed at the Institute (IGE) and considered for evaluation:

1. Schmidt, M. Arold, J.: Untersuchung zur Erschließung niedrig investiver Energieeinsparpotenziale [3]
2. Schmidt, F. Stergiaropoulos, K. et. al.: REUSE - Rational Use of Energy at the University of Stuttgart Building Environment [2]
3. Grob, R. Schmidt, M. Harter, J., Bach, H.: COURAGE - Computergestützte Überprüfung von bestehenden heiz- und raumlufttechnischen Anlagen [4]
4. Grob, R. Kopetzky, R. Schmidt, F.: WIMA - Wissensbasiertes Energiemanagement- eine neue Dienstleistung für mittelständische Unternehmen [5]
5. Schmidt, M. Stergiaropoulos, K.: EMSLE - Energie Management System für die Stadt Leinfelden-Echterdingen [6]
6. Schmidt, M.; Stergiaropoulos, K.; Schmidt, F.: CAMPUS - Energie- und Gebäudemanagement im Campus Pfaffenwald und seine Auswirkungen auf die Effizienz der Energieerzeugung [1]

Both, own research activities and experiences from other research projects such as the guidelines and reports to the energetic inspection of ventilation systems from the Fachinstitut Gebäude-Klima e.V. (FGK) [16] according to § 12 of the German Energy Saving Ordinance (EnEV) [15] have been included.

The housing company in Mannheim GBG [18] has good experiences in the energy-efficient operation of their heating installations. An important basis is the hydraulic balance of the heating installation which in practice has been executed insufficiently or mostly not all. The housing company GBG has gained a wealth of experience in this field.

Own experiences and literature sources lead to a collection of measures which are worked in the expert system. The expert system is described detailed in the following chapter.

7 Conclusion

A so called expert system was developed with the aim of enabling the operating personnel of non-residential buildings to identify and transfer low-invest energy saving measures. The structure of the expert system is designed to get the best possible acceptance of the user. For this the form of a check list was chosen, because thereby many information can be recorded and the user is very flexible and e.g. can ignore questions he can’t answer. This is very important, because the user should not give up in frustration.

The catalogue of possible measures was based on experiences gained by the Institute and other bodies. Furthermore, the requirements on the energetic inspection of the EnEV (German Energy Saving Ordinance) and the EPBD were respected. A first test run with the operating staff of a real building showed that such test runs give new impulses from practice which could be used to ameliorate particularly the user-friendly application. Therefore, it seems useful to examine and to further adopt the expert system in a longer testing phase with more test-runs etc. The most important task in this process is to improve the questions wording.

8 References

[1] Schmidt, M.; Stergiaropoulos, K.; Schmidt, F.: CAMPUS - Energie- und Gebäudemanagement im Campus Pfaffenwald und seine Auswirkungen auf die Effizienz der Energieerzeugung, Schlussbericht, LHR 01-05, Stuttgart 2005

[2] Schmidt, F. Stergiaropoulos, K. et. al.: REUSE - Rational Use of Energy at the University of Stuttgart Building Environment, Technischer Abschlußbericht BU 343/94 DE, Universität Stuttgart IKE-Bericht 4–151. Stuttgart 1999

[3] Schmidt, M.; Arold, J.: Untersuchung zu niedriginvestiven Einsparpotenzialen, Schlussbericht, IGE-09-09, Stuttgart 2009

[4] Grob, R. Schmidt, M. Harter, J. ,Bach, H.: COURAGE – Computergestützte Überprüfung von bestehenden heiz- und raumlufttechnischen Anlagen, Schlussbericht, BMWi 0329815A/3, Universität Stuttgart, IKE - Lehrstuhl für Heiz- und Raumlufttechnik, Stuttgart 2002

[5] Grob, R. Kopetzky, R. Schmidt, F.: WIMA - Wissensbasiertes Energiemanagement- eine neue Dienstleistung für mittelständische Unternehmen, Schlussbericht BMBF 01HW0161, Stuttgart 2003

[6] Schmidt, M. Stergiaropoulos, K.: EMSLE Energie Management System für die Stadt Leinfelden-Echterdingen, Schlussbericht, LHR 7-33, Stuttgart 2004

[7] EPBD Richtlinie 2002/91/EG des europäischen Parlaments und des Rates vom 16. Dezember 2002 über die Gesamtenergieeffizienz von Gebäuden, Amtsblatt der europäischen Gemeinschaften, 2003, Nr. L1, S.65ff

[8] DIN EN 15378: 02-2006 Heizsysteme in Gebäuden- Inspektion von Wärmeerzeugern und Heizsystemen.

[9] DIN EN 15239: 08-2007 Lüftung von Gebäuden- Gesamtenergieeffizienz von Gebäuden-Leitlinien für die Inspektion von Lüftungsanlagen.

[10] DIN EN 15240: 08-2007 Lüftung von Gebäuden- Gesamtenergieeffizienz von Gebäuden-Leitlinien für die Inspektion von Klimaanlagen.

[11] VDMA 24186-1: 2002–09 Leistungsprogramm für die Wartung von technischen Anlagen und Ausrüstungen in Gebäuden: Teil 1 Lufttechnische Geräte und Anlagen

[12] VDMA 24186-2: 2007–01 Leistungsprogramm für die Wartung von technischen Anlagen und Ausrüstungen in Gebäuden: Teil 2 Heiztechnische Geräte und Anlagen

[13] VDMA 24186-3: 2002–09 Leistungsprogramm für die Wartung von technischen Anlagen und Ausrüstungen in Gebäuden: Teil 3 Kältetechnische Anlagen zu Heiz- und Kühlzwecken

[14] VDMA 24186-4: 2002–09 Leistungsprogramm für die Wartung von technischen Anlagen und Ausrüstungen in Gebäuden: Teil 4 MSR Einrichtungen und Gebäudeautomationssysteme

[15] EnEV 2009: Verordnung zur Änderung der Energieeinsparverordnung, Bundesgesetzblatt, 2009, Nr.23, S. 954 ff

[16] Händel, Claus: Energetische Inspektion von Lüftungs-und Klimaanlagen: 5 FGK Status-Report 3 Aufl. 2010

[17] Tackobst consortium (GBG Mannheim): Pedagogical guide. Tackling obstacles to energy efficiency in social housing. Bericht, Mannheim 2009

[18] *Fielenbach, Hubert:* Praxisbericht. Optimierung von Heizungsanlagen durch geringinvestive Maßnahmen, Vortrag, 2009

[19] DIN EN 15251: 2007-08 Eingangsparameter für das Raum-klima zur Auslegung und Bewertung der Energieeffizienz von Gebäuden – Raumluftqualität, Temperatur, Licht und Akustik

[20] DIN EN 13779: 2007–09 Lüftung von Nichtwohngebäuden – Allgemeine Grundlagen und Anforderungen für Lüftungs- und Klimaanlagen und Raumkühlsysteme

Modelling of Absorption Chillers by Means of Different Approaches

Joan Carles Bruno, Jerko Labus, David Martínez-Maradiaga, Alberto Coronas

Universitat Rovira i Virgili, Mechanical Engineering Department, CREVER - Group of Applied Thermal Engineering

Abstract

The growing market for heating and air-conditioning equipment for buildings and the high cost of fossil fuels followed by environmental consequences such as ozone depletion and global warming have promoted the thermally driven systems as a very attractive technology for both residential and industrial applications. Among them, thermally driven absorption systems play an important role from the energy saving point of view due to their capacity to use renewable energy sources and waste heat. High investment cost, requirement of additional equipment and only a few manufacturers in the market are some of the main reasons why small capacity absorption systems are not yet economically competitive in comparison with conventional compression systems. This indicates the need for further research especially in the field of modelling, simulation and performance assessment. The development of accurate absorption chiller models is essential since it can be used in various applications: prediction of system's performance, control and monitoring, fault detection, optimization, etc. The aim of this study is to present a comparative evaluation of five models for predicting small capacity absorption chillers performance. Physical model based on First Law of Thermodynamics was compared with four empirically based models: the Gordon-Ng model, the characteristic equation model, the artificial neural networks model and the multivariable polynomial model. These models are based on experimental data obtained in fully equipped and monitored test bench for absorption chillers and working at several steady state conditions. Data sets consist of experiments with the absorption unit working both in cooling and heating mode. The results of this study show that empirical models are accurate, simple to develop and suitable for those cases in which enough experimental data is available. Finally, this study can be used as a reference when selecting the appropriate modelling approach for absorption chillers and heat pumps for their integration into broader scope simulation environment such as Trnsys, Gams, etc.

Introduction and objectives

The current energy systems based on fossil fuels are largely responsible among other factors for the present environmental and economic crisis. Significant contributors to the primary energy consumption are the electrical air-conditioning units. The continued rise in living and working comfort conditions with reduced prices of air-conditioning units and lower electricity prices have caused a great expansion of these systems. The consequence is the negative impact on electricity demand and environment. Since absorption units have a lower requirement for electrical power, these units have been promoted as a measure to reduce utility demand peaks. Another advantage of absorption units is that working fluids are not harmful to the environment, unlike the CFC's and HCFC's refrigerants used in compression equipment. In a single-effect absorption refrigeration cycle (Fig. 1) the role of the compressor in compression cycle is replaced by what is called a "thermal compressor" consisting of generator, absorber, solution heat exchanger, solution pump and throttling valve. The absorption cycle uses a heat-driven concentration difference to move refrigerant vapour from the evaporator to the condenser. Recently, there is a rising tendency in demand for small capacity absorption systems in buildings. However, high investment cost, requirement of additional equipment (heat rejection system for the condenser and absorber) and only a few manufacturers are the main causes why this systems are not yet economically competitive with conventional compression systems. Simple but rigorous modelling and simulation approaches to calculate absorption systems performance can contribute to overcome these barriers.
Thermodynamic models are very demanding since they require comprehensive knowledge of the absorption cycle including all internal state points. The model needs lots of input parameters such as

overall heat transfer coefficients (U) and heat transfer areas (A) of all the main components, solution flow rate, working fluid properties and water side flows and temperatures as well as some additional assumptions for convenience of modelling. In most of the cases, especially with commercial units, the internal parameters are not available. This is the reason why thermodynamic models are more adequate during the design stage of absorption equipment [1]. The computation time in simulation software packages is very long since these models require some iteration steps. The annual simulations of different systems on hourly time step basis takes a long time usually with convergence problems. Thus, there is a need for simple but reliable models which can provide sufficiently good representation of the absorption machine behaviour based only on available external parameters (experimental measurements or manufacturer catalogue data). These simple models could be easily incorporated in simulation programs or used in fault detection and control applications. Contrary to the physical models, the empirical and semi-empirical models require less time and effort to develop and computation time. The parameters and fitting coefficients of the models are determined using the regression method or minimizing algorithms applied to a data set obtained from manufacturer catalogues or experimental measurements.

The studies about development of empirically based models for absorption equipment have been reported by several authors. Gordon and Ng [2] developed a general model for predicting absorption chillers performance. The model lays both on physical and empirical principles. The physical principles that govern the performance of the absorption chiller are fitted to the experimental or manufacturer data by using a regression method. Ziegler et al. [3] developed a model (Characteristic equation method) which predicts the performance of the absorption chiller by two simple algebraic equations: one for cooling capacity and one for driving heat input. The Artificial Neural Networks (ANN) approach for performance analysis of an absorption chiller was proposed in the study of Sozen and Akcayol [4] among others. The ANN model employed only working temperatures of four components as input parameters to predict the performance of the chiller. The ANN model belongs to the black-box approaches where the estimated parameters of the model have no physical interpretation. Regardless the numerous studies on the modelling of absorption equipment, literature review shows that there is a huge gap when it comes to comprehensive comparative studies on different modelling techniques for predicting absorption equipment performance in a similar way as Lee and Lu [5] did for the case of vapour-compression chillers.

The main aim of this paper is to present a comparative evaluation of different modelling approaches for predicting the performance of absorption systems. For that purpose, the absorption machine Rotartica Solar 045 (Fig. 2) was selected as case study. The advantage of this machine is that it can operate both as chiller and as heat pump. The experimental data obtained in a fully equipped and monitored test bench and also manufacturer catalogue data were used as a base for the modelling methods comparison. The study examines five different models when absorption machine operates as chiller (thermodynamic model, the adapted Gordon-Ng model, the adapted characteristic equation model, the artificial neural networks model and the multivariable polynomial model) and three models when it operates as heat pump (the adapted characteristic equation model, the artificial neural networks model and the multivariable polynomial model).

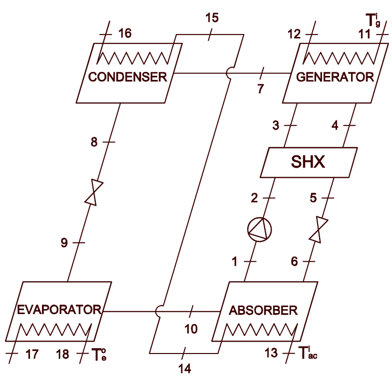


Fig. 1. Single-effect Absorption cycle

Fig. 2. Rotartica Solar 045 absorption chiller

Modelling methods

Thermodynamic model (TD)

A general thermodynamic model is developed based on data from manufacturer's catalogue [6]. Some basic assumptions had to be considered for convenience in modelling. With reference to Fig. 1, these assumptions are the following: at streams 1, 4 and 8 there is only saturated liquid; at stream 10 there is only saturated vapour; there are no pressure drops except through the solution pump and throttling devices; all the heat exchangers have constant heat transfer coefficients; the absorber and condenser are connected in a series flow configuration; vapour flashes as liquid passes through throttling devices; refrigerant flow is constant; the solution pump is ideal; throttling devices are isentropic and there are no jacket heat losses. Based on these assumptions, program code for the absorption chiller model can be written by performing mass and energy balances for each component. The detailed procedure for this modelling approach can be found in [7].

Generator:

$$\dot{m}_3 = \dot{m}_4 + \dot{m}_7 \tag{1}$$

$$\dot{m}_3 \cdot x_3 = \dot{m}_4 \cdot x_4 \tag{2}$$

$$Q_g = \dot{m}_4 \cdot h_4 + \dot{m}_7 \cdot h_7 - \dot{m}_3 \cdot h_3 \tag{3}$$

$$Q_g = \dot{m}_{11} \cdot \left(h_{11} - h_{12}\right) \tag{4}$$

Condenser:

$$Q_c = \dot{m}_7 \cdot \left(h_7 - h_8\right) \tag{5}$$

$$Q_c = \dot{m}_{15} \cdot \left(h_{16} - h_{15}\right) \tag{6}$$

Throttling valves:

$$h_8 = h_9 \quad \text{and} \quad h_5 = h_6 \tag{7}$$

Evaporator:

$$Q_e = \dot{m}_9 \cdot \left(h_{10} - h_9\right) \tag{8}$$

$$Q_e = \dot{m}_{17} \cdot \left(h_{17} - h_{18}\right) \tag{9}$$

Absorber:

$$Q_a = \dot{m}_{10} \cdot h_{10} + \dot{m}_6 \cdot h_6 - \dot{m}_1 \cdot h_1 \tag{10}$$

$$Q_a = \dot{m}_{13} \cdot \left(h_{14} - h_{13}\right) \tag{11}$$

Pump:

$$\dot{W} = \dot{m}_2 \cdot h_2 + \dot{m}_1 \cdot h_1 \tag{12}$$

Solution heat exchanger:

$$\dot{m}_2 \cdot h_2 + \dot{m}_4 \cdot h_4 = \dot{m}_3 \cdot h_3 + \dot{m}_5 \cdot h_5 \tag{13}$$

The enthalpy values needed to evaluate these equations must be obtained from property data sources of the working fluid. The enthalpy values depend on thermodynamic state in each process stream. Absorption cycle model equations must be solved simultaneously. However, since the manufacturer's catalogue provides only nominal external operating conditions, UA values for components and internal variables are not available. The only available variables are the following

(Table 1): hot water inlet temperature, cooling water inlet temperature, chilled water outlet temperature, mass flow rates in external circuits and heat loads in the generator, evaporator and the sum of the absorber and condenser loads. With the developed model for a generic single-effect H_2O/LiBr absorption chiller with external circuits the degrees of freedom are 2C+12, where the C is the number of components in the working pair (two in our case). For this particular chiller configuration the number of degrees of freedom is reduced from 16 to 12 using the common assumptions made for absorption cycle: pure refrigerant at the generator's outlet, saturated vapour at the evaporator's outlet and series flow configuration (t_{14}=t_{15}) Consequently, this model requires 12 input parameters. In order to calculate UA values, we applied a backward methodology. Three additional assumptions were necessary for this. First, an initial value for solution heat exchanger effectiveness (**e**$_{shx}$=0.7); second, an initial value for solution pump flow rate (0.05 kg/s) and third, total absorber and condenser load is divided with ratio 0.6:0.4, respectively. Assuming "pinch" temperature for each component, using known external parameters and heat loads, thermodynamic model of absorption cycle was developed in Energy Equation Software (EES) environment. Once the absorption cycle is solved, we approached to the simultaneous optimization of pinch temperatures in order to adjust heat loads of each component to the nominal values from manufacturer's catalogue. Afterwards, the UA values of each component were calculated by simple UA formulation:

$$UA = \frac{Q_k}{\Delta T_{lm}} \tag{14}$$

where, ΔT_{lm} is the log mean temperature difference of each component and k depicts the component loads.

Once the UA values are estimated, they replace component heat loads as input parameters for the model. Together with known (or required) external circuit temperatures and flow rates, the model can be used to predict the absorption chiller performance.

Table 1. Input parameters for the thermodynamic model

Manufacturer data (nominal conditions)		Estimated parameters (backward modelling)	
Hot water inlet temperature, t_{11} [ºC]	90		
Cooling water inlet temperature, t_{13} [ºC]	35	UA_c [kW/K]	0.9387
Chilled water outlet temperature, t_{18} [ºC]	12	UA_g [kW/K]	1.423
Hot water flow rate, [kg/s]	0.24	UA_a [kW/K]	2.236
Cooling water flow rate, [kg/s]	0.55	UA_e [kW/K]	0.7881
Chilled water flow rate, [kg/s]	0.43	m_1 [kg/s]	0.0647
Generator load, [kW] Q_g	7.2	e_{shx}	0.669
Evaporator load, [kW] Q_e	4.5		
Absorber and condenser load, [kW] Q_{ac}	11.7		

Adapted Gordon-Ng Model (GNA)

The Gordon-Ng (GN) model for absorption chillers [2] is a semi-empirical model that is able to calculate the chiller performance through the measurements of external circuits. Experimental data is used to fit two regression parameters. These parameters have physical interpretation since the model is developed from the First and the Second laws of thermodynamics, they characterise the irreversibilities of the absorption chiller. The GN model calculates the inverse of *COP* using the following equation:

$$\frac{1}{COP} = \left[\frac{T_c^i - T_e^o}{T_e^o}\right] \cdot \left[\frac{T_g^i}{T_g^i - T_c^i}\right] + \left[\frac{1}{\dot{Q}_e}\right] \cdot \left[\frac{T_g^i}{T_g^i - T_c^i}\right] \cdot \left[\alpha_1 - \alpha_2 \cdot \frac{T_c^1}{T_g^1}\right] \tag{15}$$

where α_1 and α_2 are the regression parameters to be fitted.

As equation (15) shows, the GN model requires T_c^i as an input variable. In our study this measurement is not available. For this reason, we adapted the original model using T_{ac}^i instead of T_c^i. The validity of this assumption relies in the fact that in absorption chillers the absorber and condenser work at the same or very similar temperature level [7]. Therefore the GNA model is described by (16).

$$\frac{1}{COP}=\left[\frac{T_{ac}^i-T_e^o}{T_e^o}\right]\cdot\left[\frac{T_g^i}{T_g^i-T_{ac}^i}\right]+\left[\frac{1}{\dot{Q}_e}\right]\cdot\left[\frac{T_g^i}{T_g^i-T_{ac}^i}\right]\cdot\left[\alpha_1-\alpha_2\cdot\frac{T_{ac}^1}{T_g^1}\right] \tag{16}$$

Considering that a plot of $\frac{T_{ac}^i}{T_g^i}$ against $\left[\frac{T_g^i-T_{ac}^i}{T_g^i\cdot COP}-\frac{T_{ac}^i-T_e^o}{T_e^o}\right]\cdot\dot{Q}_e$ leads to a straight line, we can calculate α_1 and α_2 as the intercept and slope of this line using linear regression. We compare the different modelling approaches by means of the deviation between the experimental heat loads and the ones obtained by each model. When the machine operates as absorption chiller the basis of comparison are the chiller capacity and the heat input. Thus, in order to evaluate GNA model we rearranged equation (16) to obtain the chiller capacity (17). The heat input can be derived from the COP (18).

$$\dot{Q}_e=\frac{B}{1/COP-A} \tag{17}$$

$$\dot{Q}_g=\frac{B}{1-A\cdot COP} \tag{18}$$

where:

$$A=\left[\frac{T_{ac}^i-T_e^o}{T_e^o}\right]\cdot\left[\frac{T_g^i}{T_g^i-T_{ac}^i}\right] \quad ; \quad \mathrm{B}=\left[\frac{T_g^i}{T_g^i-T_{ac}^i}\right]\cdot\left[\alpha_1-\alpha_2\cdot\frac{T_{ac}^1}{T_g^1}\right] \tag{19}$$

Adapted characteristic equation method (ΔΔt')

Ziegler et al. [3] developed an approximate method for modelling absorption chillers able to represent both cooling capacity and driving heat input by means of simple algebraic equations. These equations are expressed as a function of so-called characteristic temperature function (ΔΔT) which depends on the average temperature of the external heat carrier fluids. One of the main assumptions of the authors is that the heat transfer processes in absorption chillers dominate their behaviour. Starting from the heat transfer equations in the four major components where the transferred heat is related to the driving temperature difference in the heat exchangers and by combining them with Duhring's rule the authors determine the relationship between the external temperatures (20).

$$\Delta\Delta T=\left(t_g-t_a\right)-R\cdot\left(t_c-t_e\right)\approx t_g-\left(1-R\right)\cdot t_{ac}+R\cdot t_e \tag{20}$$

In this way, a complex response to all external heat carrier temperatures is reduced to a linear function of heat flow and the external temperatures. R is a constant equal to 1.1 (for water/LiBr systems) used to relate the slope of vapour pressure line to the one of pure water. A simple linear correlation is very convenient, but it has been found that the predicted performance of the cooling capacity deviates considerably from the linear behaviour, for instance, at high driving temperatures, due to higher internal losses. With respect to that, an adapted characteristic equation method was proposed by Kuhn and Ziegler [8]. In this improved model, a numerical fit of catalogue or experimental data is used to improve the characteristic equation. Thus, the adapted characteristic temperature function (ΔΔT') takes the form:

$$\Delta\Delta T' = t_g - a \cdot t_{ac} + e \cdot t_e \tag{21}$$

And the linear characteristic equation for component loads takes the form:

$$\dot{Q}_k = s' \cdot \Delta\Delta T' + r \tag{22}$$

Combining (24) and (22) yields one correlation which represents the thermal performance of the components as a function of the external arithmetic mean temperatures of the generator (t_g), absorber-condenser (t_{ac}) and evaporator (t_e), when the external flow rates are constant.

$$\dot{Q}_k = s' \cdot t_g - s' \cdot a \cdot t_{ac} + s' \cdot e \cdot t_e + r \tag{23}$$

The four parameters (s', a, e and r) are then estimated by using the multiple linear regression algorithm to fit the catalogue or experimental data. This algorithm chooses regression coefficients to minimise the residual sum of squares. The analyses of Puig et al. [9] confirmed the capability of $\Delta\Delta T'$ method to obtain good results and also better accuracy than the original method $\Delta\Delta T$. Finally, combining the obtained characteristic functions (23) with equations for external arithmetic mean temperatures (24)-(26) and with external energy balances (27)-(29) results in a system of six equations with six unknowns which can easily be solved. The developed model requires only three temperatures (one from each of the external circuits) and fixed flow rates of external heat carriers to predict the performance of the absorption chiller or heat pump.

$$t_e^i = 2 \cdot t_e - t_e^o \tag{24}$$

$$t_g^o = 2 \cdot t_g - t_g^i \tag{25}$$

$$t_{ac}^o = 2 \cdot t_{ac} - t_{ac}^i \tag{26}$$

$$\dot{Q}_e = 2 \cdot m_e \cdot Cp_e \cdot \left(t_e - t_e^o\right) \tag{27}$$

$$\dot{Q}_g = 2 \cdot m_g \cdot Cp_g \cdot \left(t_g^i - t_g\right) \tag{28}$$

$$\dot{Q}_{ac} = 2 \cdot m_{ac} \cdot Cp_{ac} \cdot \left(t_{ac} - t_{ac}^i\right) \tag{29}$$

Despite that this method is based on numerical fit to experimental or catalogue data, it would not be right to classify it just as black-box. Just as in the case of GNA model, term semi-empirical would be more appropriate knowing that these equations contain in simplified form the complete thermodynamic information of the absorption system. The characteristic equation method can be used in the same way to model the absorption heat pump behaviour.

Artificial Neural Networks (ANN)

ANN methodology is a group of computer methods for modelling and pattern recognition based on non-linear transformation functions, connected in a way similar to neurons in the human brain. There are many types of ANN architectures in the literature; however, the most common network structure used for prediction is the multi-layer feed-forward network with back-propagation. In feed-forward networks, signals flow forward from inputs, through one or more hidden layers of sigmoid neurons before reaching the output layer of linear neurons. The weights connecting the transformation functions with the dependant variables do not represent any physical relationship; hence artificial neural networks are black-box models. The difference between the network output obtained and the desired output (target) is compared and iterated again until the output reaches the prescribed tolerance value.

Multivariable Polynomial Regression (MPR)

MPR models are another type of black-box models. In this study we used 2^{nd} order polynomials to calculate the absorption machine heat loads working both as a chiller and as a heat pump.

When the absorption machine works as a chiller the MPR models calculate the thermal loads using the measurements of external circuits: generator inlet temperature, condenser inlet temperature, and evaporator outlet temperature. In the case that the absorption machine works as heat pump the MPR models calculate the thermal loads using the generator inlet temperature, condenser outlet temperature, and evaporator inlet temperature. The generalized model is represented by the following equation:

$$\dot{Q}_k = \beta_{0,k} + \beta_{1,k} t_g + \beta_{2,k} t_{ac} + \beta_{3,k} t_e + \beta_{4,k} t_g t_{ac} + \beta_{5,k} t_g t_e + \beta_{6,k} t_{ac} t_e + \beta_{7,k} \left(t_g\right)^2 + \beta_{8,k} \left(t_{ac}\right)^2 + \beta_{9,k} \left(t_e\right)^2 \quad (30)$$

Experimental data

Experimental database consists of 41 data sets of the absorption machine operating at steady state conditions. Each data set represents an average value of steady state operation during 30 min period in 1s intervals. These data were obtained in a multifunctional test bench at the Rovira i Virgili University with the Rotartica absorption machine tested both as chiller and as heat pump. The detailed test procedure and the experimental results were reported in our previous study [10]. Thus, the absorption chiller models were based on these measurements at constant flow rates (1.2, 1.2, 2.0 m^3/h for hot, chilled and cooling water circuit, respectively) when the temperatures of external circuits were varied: hot water inlet temperature in the range [80-100ºC], inlet cooling water temperature in the range [25-40ºC] and outlet chilled water temperature in the range [7-15ºC]. The absorption heat pump models are also based on the measurements at constant flow rates with only the difference that controlled temperature parameters were chosen as: inlet hot water in the range [85-95ºC], outlet cooling water in the range [40-48ºC] and inlet chilled water temperature in the range [15-25ºC].

Results and discussion

In this paper, we developed and compared five different models of the absorption machine operating as a chiller (TD, GNA, ΔΔt', ANN and MPR) and three models operating as a heat pump (ΔΔt', ANN and MPR). The TD model developed for chiller mode is not valid for heat pump mode since the operating conditions of each mode are very different. Using the same parameter values obtained for chiller mode to simulate the performance of the absorption machine working as heat pump would introduce too much error. In the case of the GNA model, its development was made for absorption chillers. A development of GNA for absorption heat pumps would require expressing the performance in terms of the useful heat. Furthermore, the assumptions about the dominant irreversibilities acting in absorption heat pumps should be somehow different to the ones acting in chiller mode because the operating conditions are also significantly different.

Model parameters

GNA Model

Two linear regression coefficients for the GNA model, α_1=16.5931 and α_2=18.7232, were obtained after performing numerical fit of the absorption chiller experimental data.

Characteristic Equation Model

The same experimental data set was applied for the ΔΔT' method. Multiple regression fit results in the following coefficients for characteristic functions of the absorption chiller (Table 2). The same method was useful for modelling the performance of the absorption heat pump. Table 2 also shows the numerical fit for the absorption heat pump data set.

Table 2. Multiple regression fit parameters for the characteristic Equation method

	Chiller				Heat Pump			
	s'	*s'·a*	s'·e	*r*	*s'*	*s'·a*	s'·e	*r*
$\dot{Q}_e$	0.1937	0.504	0.4498	0	0.2264	0.5693	0.4093	0
$\dot{Q}_{ac}$	0.4422	0.989	0.7084	0	0.5148	1.1909	0.7755	0
$\dot{Q}_g$	0.234	0.464	0.2614	0	0.2861	0.6076	0.2861	0

ANN Model

ANN models for both absorption chiller and heat pump were developed in MatLab NN Toolbox. By applying trial and error rule to determine the number of neurons in the hidden layer and the number of hidden layers, the adopted topology for ANN models was (3-7-1) as shown in Fig. 3. One input layer with three variables, one hidden layer with seven neurons and one output layer with one output: a component load (three different models for the heat released or supplied to the evaporator, absorber/condenser or generator of the absorption chiller and the same for the heat pump). The training of the ANN was based on error back propagation technique using the Levenberg-Marquardt algorithm of optimization. The input parameters were normalized in the [0.2, 0.8] range. A hyperbolic tangent sigmoid function (*tansig*) was used in the hidden layer and the linear transfer function (*purelin*) was used in the output layer. To test the robustness and predict the ability of the models, the experimental database was split: a total of 70% was used for training, 20% for validation and 10% for testing.

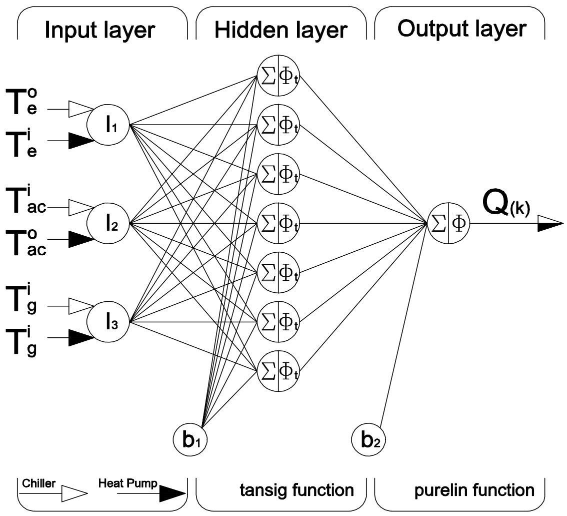


Fig. 3 ANN modelling

The ANN absorption chiller and heat pump models for calculating thermal loads are given by the generalized equation (31):

$$\dot{Q}_k = \sum_i^j \left[LW_{(1,j)} \cdot \left(\frac{2}{1+\exp\left(-2\left(\sum_1^R IW_{(j,R)} I_R + b_{1(j)}\right)\right)} - 1 \right) \right] + b_2 \qquad (31)$$

where I is the input, R is the number of the input (R=3), b_1 are biases in the hidden layer, b_2 are biases in the output layer, J is the number of neurons in the hidden layer (J=7), and IW and LW are the weights in the input and output hidden layer, respectively. Table 3 shows the statistical parameters of the absorption chiller and heat pump models obtained by ANNs.

Table 3. ANN coefficients

Input weights -chiller						Input weights –heat pump					
IW(Q_e)			**IW(Q_g)**			**IW(Q_{ac})**			**IW(Q_g)**		
9.5922	1.1127	-2.8749	6.9474	-5.2149	8.213	-0.9766	7.2184	-2.4426	5.7615	4.6297	3.0687
-2.2934	1.9244	-9.3767	0.2142	-7.4426	-7.6131	-4.316	8.3124	2.0374	-1.6226	-9.1277	1.5826
-6.9985	1.3332	4.1288	-5.6933	4.2097	7.1662	1.4565	-13.3316	2.4926	-3.4662	6.9294	-1.2433
-7.0962	3.5343	3.175	10.37	3.3326	3.173	10.0822	8.7378	-1.6645	0.5414	6.6856	5.1237
5.1588	-10.0578	20.6436	6.2784	-7.5392	3.4556	0.0171	-10.2347	-8.7692	3.0502	-6.7519	-8.8014
-0.7916	1.9889	-0.9441	0.8029	-1.7402	1.0614	11.784	9.2453	8.2117	-3.0143	-7.2717	-2.6744
6.0008	5.0222	10.4135	10.3616	-1.3676	-3.5351	1.7143	-0.9211	0.2452	7.4089	-4.9996	1.9601
Output weights-chiller											
LW(Q_e)	-3.1826	-1.5257	1.9204	-1.8471	-1.154	-6.3839	-3.8225				
LW(Q_g)	0.3898	-2.6433	0.7111	-1.3186	0.9854	5.9236	-0.2167				
Output weights–heat pump											
LW(Q_c)	-4.3136	-2.5754	-4.1314	1.9932	-1.9553	0.2218	6.599				
LW(Q_g)	-0.6257	1.2389	-2.8104	0.4258	-0.3194	-1.898	0.7901				
Biases in input and hidden layer-chiller						Biases in input and hidden layer-heat pump					
b1(Q_e)	**b1(Q_g)**	**b2(Q_e)**	**b2(Q_g)**			**b1(Q_c)**	**b1(Q_g)**	**b2(Q_c)**	**b2(Q_g)**		
-9.0668	8.1163	5.7146	5.4579			-2.1151	-11.0396	5.0505	4.4341		
6.9072	-0.3853					1.7136	5.1286				
-6.8933	-6.4215					-5.2873	-0.9298				
-3.8973	-2.7785					-1.7755	-7.119				
-10.6053	-3.4482					6.6046	3.7294				
-0.1994	0.2362					1.384	4.7536				
0.9475	-3.074					-0.599	-0.2156				

MPR Model

In the case of MPR models, Table 4 shows the regression fitting parameters ($\beta_{i,k}$) for the different heat loads (k) when 2nd order polynomials were used to model both the absorption chiller and heat pump.

Table 4. Fitting coefficients for MPR model

	Chiller		Heat Pump	
(k)	Q_e	Q_g	Q_{ac}	Q_g
β_0	8.20E+01	-5.80E+00	9.97E+01	8.58E+00
β_1	-1.42E+00	2.53E-01	-1.67E+00	-1.56E-02
β_2	1.19E-01	-6.58E-01	-9.97E-01	-3.34E-01
β_3	-2.84E+00	1.32E+00	-9.10E-02	-2.71E-02
β_4	-4.21E-03	3.32E-03	2.49E-02	1.05E-02
β_5	2.90E-02	-9.43E-03	7.78E-03	4.81E-03
β_6	1.28E-02	-9.98E-03	-2.27E-03	-3.67E-03
β_7	7.51E-03	-1.99E-04	5.75E-03	-1.04E-03
β_8	-4.62E-03	9.91E-04	-2.76E-02	-1.30E-02
β_9	5.24E-03	7.31E-03	7.35E-03	3.55E-03

Comparison of the models

The simulations of the absorption chiller show a great diversity when different modelling approaches are used. Figure 4 represents the chiller capacity as a function of the chilled water outlet temperature at three different cooling water inlet temperature levels. This figure shows manufacturer, experimental and simulated data when the absorption machine works as a chiller. If we have a look into the chiller capacity, presented in this figure, one of the first differences we can notice is that the experimental values are lower than the catalogue values. At first sight, one of the facts which might cause that are the flow rates of chilled water (0.43 kg/s) and cooling water (0.55 kg/s) circuits different from nominal values (0.44 kg/s for chilled water and 0.56 kg/s for cooling water). On the other hand, the sensitivity analysis from our previous study [10] indicates that the influence of flow rates in a narrow range such is the case with Rotartica does not affect the performance of the absorption chiller significantly. This leads to the conclusion that the real performance of the machine could be lower than the one reported by manufacturer. Also, it can be seen that data obtained from thermodynamic simulation are in close agreement with catalogue data, especially for curve with hot water inlet temperature at 90ºC and cooling water inlet temperature at 35ºC. This agreement between catalogue data and the TD model is reached because model parameters were estimated using the nominal conditions specified at the manufacturer catalogue. The discrepancy between the simulation and catalogue data increases moving away from this curve, which is the same as moving away from nominal conditions. The reason for that is that the UA values are not constant as we assumed. The disadvantages of the thermodynamic models with constant UA values were also reported in the study of Kim et al. [12]. The empirically-based models of the absorption chiller have very good agreement with experimental data, with exception of GNA model. Obviously, the reason is that experimental data were used to fit the models parameters.

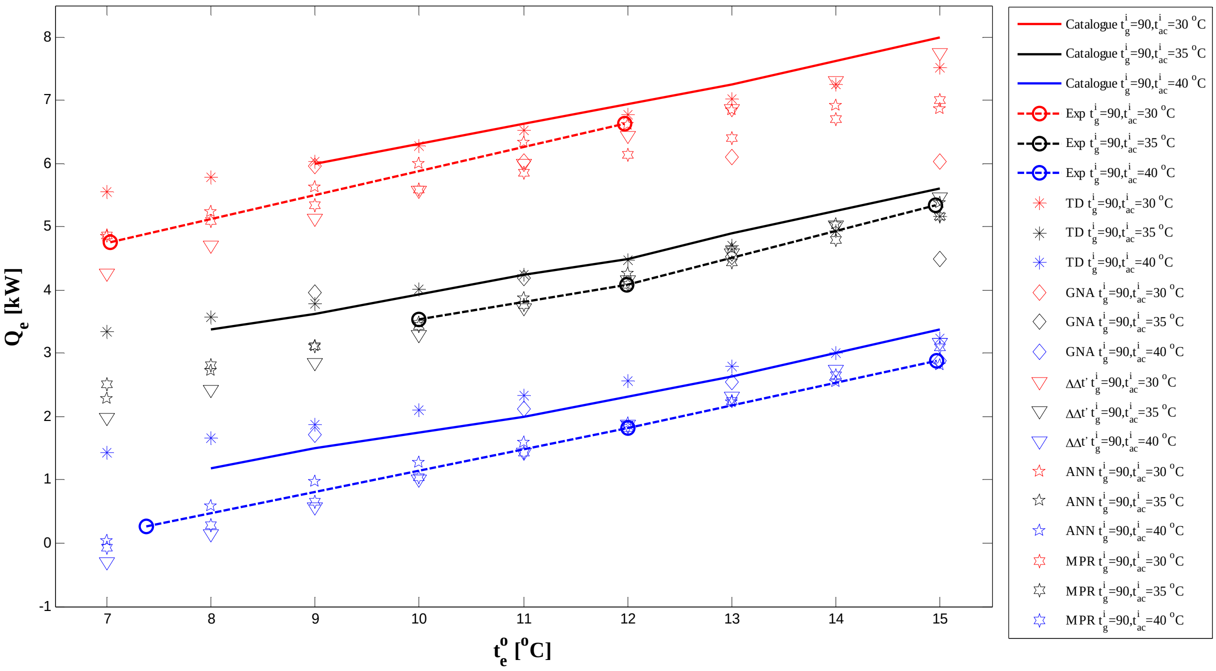


Fig. 4. Comparison of the absorption chiller models with catalogue and experimental data

The goodness-of-fit of models is usually evaluated in terms of statistical parameters. The coefficient (R^2) is used as an indicator of how well a model is able to predict an output value. The root-mean-square error (RMSE) is another useful indicator for comparing the predicting performance of the different models. RMSE can be considered as a measure of precision. RMSE is used to obtain the confidence interval (CI) which is a way to visualize the precision of each model. Narrower CI indicates better precision since RMSE is lower.

Normally, CI is constructed by using the standard deviation:

$$CI = \overline{y} \pm z \cdot \sigma \tag{32}$$

where $\overline{y}$ is the mean value of the measurement, σ is the standard deviation of the measurement, and z is the score of the standard normal distribution. Using the RMSE instead of and assuming a confidence level of 95% the CI can be estimated as:

$$CI = \overline{Q_k} \pm 1.96 \cdot RMSE \tag{33}$$

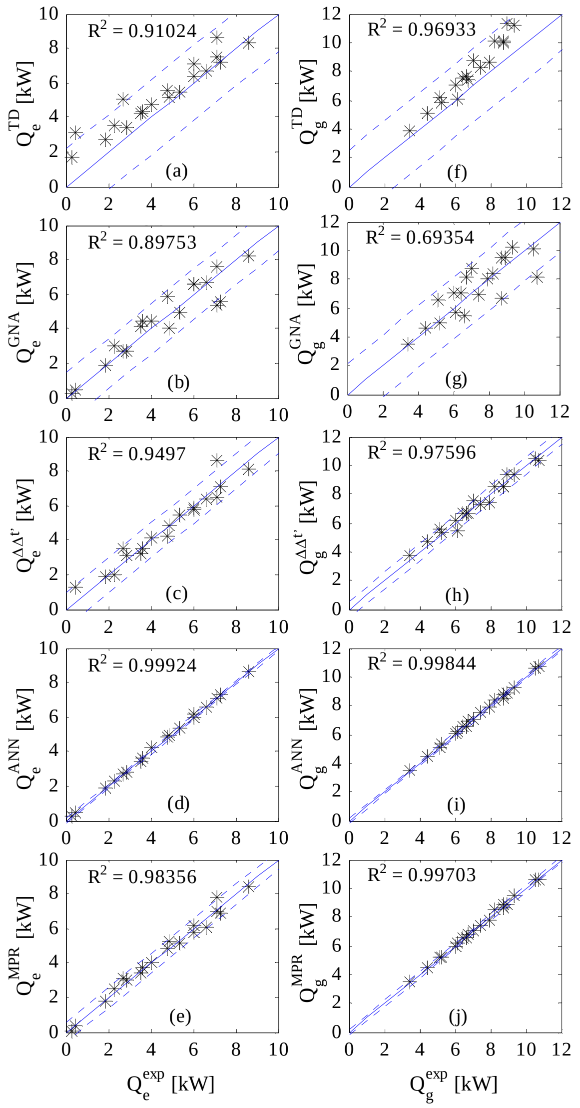
We also use the coefficient of variation of the root-mean-square error (*CV*) in order to compare the models in terms of predicting capabilities. *CV* is defined as RMSE divided by the dependent variable average (34).

$$CV = \frac{RMSE}{\overline{Q_k}} \cdot 100\% \tag{34}$$

The five different absorption chiller models are compared in Fig. 5 through the predicted chiller capacity and driving heat input ($\dot{Q}_e$ and $\dot{Q}_g$). R^2 and CI (in the form of dashed lines) of each model are shown as parameters that allow the comparison of the predictive capabilities. It is obvious that better accuracy can be obtained from the pure black-box models rather than the thermodynamic and semi-empirical models. R^2 of TD model (both for $\dot{Q}_e$ and $\dot{Q}_g$) is greater than 0.90, indicating a good fit. On the other hand, Fig. 5a and Fig. 5f show that most of the predicted values lie above the diagonal which indicates the best fit. This means that the TD model overestimates $\dot{Q}_e$ and $\dot{Q}_g$ because it does not take in account pressure drops, heat leaks, and other irreversibilities. In contrast of the TD model, the predicted values of heat loads obtained by the GNA model lay around the diagonal, due to fact that the GNA model takes into account the process irreversibilities through the 2nd law of thermodynamics. When comparing R^2, GNA models perform worse than TD models, but in terms of precision GNA models perform better than TD models because they have narrower confidence interval (RMSE of GNA models is lower than RMSE of TD models). ΔΔt' models predict chiller's behaviour much better than the previous two models, but the best fits are obtained with ANN and MPR models ($R^2 > 0.99$).

In the case of the absorption heat pump mode, Fig. 6 shows the prediction for useful and driving heat ($\dot{Q}_{ac}$ and $\dot{Q}_g$) obtained by ΔΔt', ANN and MPR modelling methods. ΔΔt' models (Fig. 6a and Fig. 6d) for heat pump mode have much better fits when compared with the models for chiller mode ($R^2 >$ 0.98). Again, the best fit is obtained with black-box models, especially with ANN method where the coefficients of determination were higher than 0.999. The reason for such a good fit of all three methods in the case of absorption heat pump is probably the narrow range of operating conditions during the tests which were used to develop the models.

Maybe the best visualization of the predicting capabilities using different modelling approaches is with respect to the CV indicator as shown in Fig. 7. If we assume that around 10% deviation of CV is acceptable to get a satisfactory prediction, it is clear that the developed TD and GNA models cannot pass this threshold. The TD model is a good approach for the study of absorption chillers and heat pumps; however it is not an appropriate approach if there are not enough data (internal measurements) to reliably estimate the numerous parameters that describe the system. No matter that GNA model does not represent correctly all the areas of the part load, it can be still used in simulation programs due to its simplicity. However, the results of our study indicate that more appropriate would be use of one of the other three methods in order to obtain better accuracy. Among them, all the models have CV values lower than 5%, except in the cases of Q_e^{MPR} and $Q_e^{\Delta\Delta t'}$ for chiller mode and $Q_e^{\Delta\Delta t'}$ for heat pump mode. Also, it is important to mention the importance of the database quality for the development of empirical models. Reliable data (reconciled measurements, accurate sensors, true steady-state data, etc.) reduce the effect of random errors in the data fitting. This improves the statistical indicators value such as R^2 and CV and therefore improves the accuracy and precision of the models.



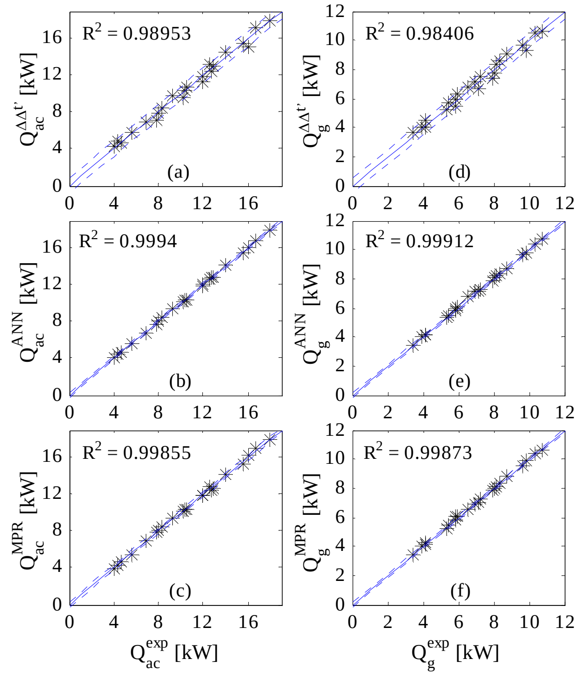


Fig. 5. Comparison between the measured and predicted evaporator and generator loads working at cooling mode

Fig. 6. Comparison between the measured and predicted useful and driving heat loads working at heat pump mode

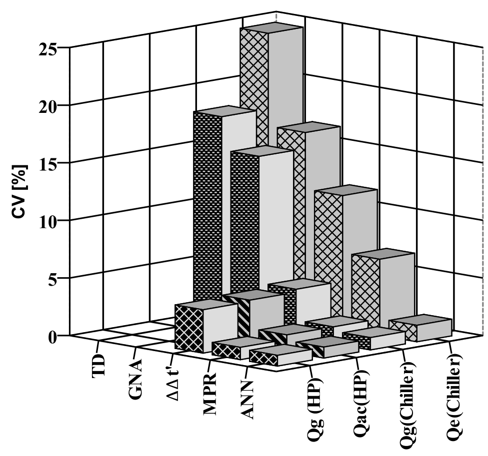


Fig. 7. CV comparison of different modelling methods

Conclusions

The objectives of this study were to provide a background of different modelling methods for absorption chillers and heat pumps and their evaluation. Using both physical and empirical approaches, several models have been developed based on manufacturer catalogue and experimental data from our test bench. All the models are based only on the measured variables from the external water circuits (only TD model requires some additional assumptions). The results confirmed that the TD model is more suitable for design phase of absorption equipment and not for simulation packages due to its complexity and numerous iterations which can cause problems in simulations for the whole year period. The constant UA values are not an appropriate approach, because the deviations increase significantly moving away from the nominal conditions. This is clearly visible through the poor statistical parameters such as R^2 and CV. Between the two semi-empirical models compared (GNA and $\Delta\Delta t'$), the second showed much better prediction capabilities having an average CV value less than 6% for all models. Higher deviation was obtained only in case of $Q_e^{\Delta\Delta t'}$(11%). Nevertheless, the best prediction was obtained with the black-box models (2nd order MPR and ANN), particularly with ANN in which case the coefficients of determination was very high (R^2>0.998) and coefficient of variation of root-mean-square error very low (CV<1.5%).
The results of this study clearly show that any of the three different methods ($\Delta\Delta t'$, MPR and ANN) is suitable for the performance prediction of absorption systems. Very good statistical parameters indicate that they can be also used for other purposes: control and monitoring, fault detection, and optimization. With respect to that, it is very important to emphasize the significance of comprehensive and accurate data sets in order to map properly the whole performance range.

Acknowledgments

The authors would like to acknowledge financial support of this work by the Spanish Ministry of Science and Innovation, Project ENE 2009-14182.

References

[1] Florides GA, Kalogirou SA, Tassou SA, Wrobel LC. Design and construction of a LiBr-water absorption machine. Energy Conversion and Management. 2003;44(15):2483-508.
[2] Gordon JM, Ng KC. A general thermodynamic model for absorption chillers: Theory and experiment. Heat Recovery Systems and CHP. 1995;15(1):73-83.
[3] Ziegler F, Hellmann HM, Schweigler C. An approximative method for modeling the operating characteristics of advanced absorption chillers. In: 29th International Congress of Refrigeration; 1999 19.-24.09.; Sydney.
[4] Sözen A, Akçayol MA. Modelling (using artificial neural-networks) the performance parameters of a solar-driven ejector-absorption cycle. Applied Energy. 2004;79(3):309-25.
[5] Lee T-S, Lu W-C. An evaluation of empirically-based models for predicting energy performance of vapor-compression water chillers. Applied Energy. 2010;87(11):3486-93.
[6] Rotartica Solar 045, Installation and Maintenance Manual. Rotartica, S.A.
[7] Herold KE, Radermacher R, Klein SA. Absorption chillers and heat pumps. Boca Raton, FL: CRC Press, 1996.
[8] Kühn A, Ziegler F. Operational results of a 10 kW absorption chiller and adaptation of the characteristic equation. In: Proceedings of First International Conference on Solar Air Conditioning; 2005; Bad-Staffelstein, Germany.
[9] Puig-Arnavat M, Lopez-Villada J, Bruno JC, Coronas A. Analysis and parameter identification for characteristic equations of single- and double-effect absorption chillers by means of multivariable regression. International Journal of Refrigeration. 2010;33(1):70-8.
[10] Labus J, Marimon MA, Coronas A. Experimental evaluation of a small capacity H_20-LiBr absorption heat pump in cooling and heating modes. International Journal of Air-Conditioning and Refrigeration. 2010;18(4):317-25.
[11] Demuth H, Beale M, Hagan M. Neural Network ToolboxTM 6 User's Guide. Natick, MA: The Mathworks Inc, 2010.
[12] Kim DS, Infante Ferreira CA, Tanda GT, Pronk P. Optimization of a solar ammonia-water absorption chiller. In: Proceedings of the IIR Conference on Thermophysical Properties and Transfer Processes of Refrigerants; 2005; Vicenza, Italy.

Design of a comfort-based monitoring approach for energy efficiency in Sport & Recreational buildings

Gian Marco Revel, Marco Arnesano

Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica delle Marche

Abstract

This paper presents a study for the design of a monitoring approach combining measurements for both energy and comfort variables in sport and recreational facilities, i.e. buildings including several areas dedicated for sport activities (pool, fitness room, multi-sport court) and related services (changing room or office). A set of performance indicators has been defined that, beside energy consumption, are able to provide real time data regarding the comfort level of the monitored areas, based on PMV/PPD measurements. The scope is to obtain meaningful information on how energy is used in relation to the perceived comfort level, so to allow fully informed management operations. This is particularly important because of the intense activities carried out in these environments, high humidity levels in pool areas and the desire to maintain a sense of well-being. For practical development the paper describes what has to be dynamically measured, which static data are required, critical uncertainty factors and how it is possible to estimate the indicators, considering correction and normalization factors typical of sport facilities. An analysis is then performed considering and simulating a configuration with a swimming pool to preliminarily demonstrate the monitoring method feasibility. The presented work is developed as a part of the FP7 UE project SportE^2 (Intelligent Management System to integrate and control energy generation, consumption and exchange for European Sport and Recreation Buildings).

Introduction

The present work is part of the FP7 EU project SportE^2 that aims at managing and optimizing the triple dimensions of energy flows (generation, grid exchange, and consumption) in Sport and Recreation Buildings by developing a new scalable and modular BMS (Building Management System) based on smart metering, integrated control, optimal decision making and multi-facility management[1].

The European Sport and Recreation Building Stock accounts for about 1,5 Million buildings in Europe. They represent about the 8% of the overall building stock while the overall energy consumption is around 10% of the building sector. Sport facilities share some characteristics with offices and other commercial buildings, but are unique by their nature, their energy consumption profiles, the usage patterns of people inside, ownership and comfort requirements [1]. In this context the paper deals in particular with the design of a monitoring strategy (what to measure, how and where), which is at the base of the Smart Metering SportE^2 module currently under implementation. Many solutions have been previously developed to analyze energy performances in different ways [2][3], at different levels of accuracy and each tool quantifies the building energy behavior to fit user's needs [4][5], but no holistic approach specific for monitoring sport buildings can be found in the state of the art, that is the starting point of this analysis.

The basic idea of the present approach is very simple: the environment of sport facilities should be managed and controlled not only to save energy and costs, but also to maximize people comfort in all the different functional areas. If this is true for residential and office buildings, specific and adaptive comfort requirements are even more stringent for sport facilities, where users want to feel well and are very sensitive to inadequate thermal conditions also because of potential health consequences. Thus, the idea is that a smart monitoring systems should be able not only to provide detailed information on energy use and generation, but also on the perceived comfort level in the different areas. The knowledge of such real-time data could give to the facility manager the possibility to take decisions on control strategies not only necessarily based on energy savings: for example, he could decide to

[1] www.sporte2.eu

improve the comfort when the facility is crowded with customers, even if this will cost a bit more. In addition, these information can also be used to feedback automatic control and optimization strategies, as it will be implemented in the $SportE^2$ BMS.

In order to practically use thermal comfort as a performance indicator, in many recent applications PMV/PPD-based (PMV: Predicted Mean Vote, PPD: Predicted Percentage of Dissatisfied) control systems have been developed and demonstrated for residential and office buildings (e.g. [6] [7] [8]). It has also been shown that a PMV-based control system has interesting potentials for energy savings with respect to thermostatic control, for example for cooling in glass façade buildings [9]. Within $SportE^2$ project similar strategies are being implemented specifically for recreational and sport buildings. For this peculiar class of commercial buildings only very recently comfort is considered in some specific applications, e.g. for heat pump control in a swimming pool [10] or in CFD (Computational Fluid Dynamics) simulations in the design phase [11]. However a methodological approach is still missing and needed. Thus in the paper the parameters to be monitored in different sport and recreation facilities are evaluated and defined. This is important to understand the impact of each variable with respect to end use energy consumption and thermal comfort. The approach to designing the monitoring plan must be adaptable to both new and existing facilities, indoor and outdoor areas, different types of functional areas and for systems embedding RES. This type of monitoring provides useful information about energy usage profiles, seasonal changes and possible defects. Here the attention is focused on thermal comfort, but in the project also parameters related to visual comfort (luminance) and air-quality (CO, CO_2) are considered. In order to implement this smart monitoring approach, also the metrological problem of accurately measuring PMV comfort parameters in sport facilities has to be addressed. ISO Standard 7726 [12] deals with the minimum characteristics required for instruments to be used for the measurement of physical parameters. Sensor networks for PMV measurements have been developed [13] [14], but the application for sport facilities is not straightforward mainly for two reasons: i) PMV and PPD parameters are basically defined for normal living environment, so they have to be differently defined and calibrated for people doing sport activities; ii) measurements have to be performed in very large spaces (court, gyms, swimming pools, etc) with relevant air stratification, with a sufficiently cost-effective sensor network and with an accuracy suitable for feedback to the control systems. The first problem is discussed and addressed here by using a numerical simulation, whilst the second one will be presented in a future paper.

This paper presents the methodology starting from the definition of a set of performance indicators. These ,beside energy consumption, are able to provide real-time data regarding the comfort level of the monitored areas, based on PMV/PPD measurements. For practical development the paper describes what has to be dynamically measured, which static data are required, critical uncertainty factors and how it is possible to estimate the indicators, considering correction and normalization factors typical of sport facilities. An analysis is then performed considering and simulating a configuration with a swimming pool to preliminarily demonstrate the monitoring method feasibility.

Performance Indicators

When designing a monitoring system, defining the objective is essential to identify customer needs and to define the boundary of the energy metering system. Sport facilities are unique buildings for energy consumption and wide composition of functional areas. The quantities to be measured have to be defined on the base of the necessary data to support and to meet the project goal. These data are called performance metrics or indicators and are the translation of the project goals into measurable data, so they usually are used for display on an energy dashboard, reports or other user interfaces**.** Firstly the general indicators, called “primary”, are described. These are commonly used for buildings energy benchmarking. Then specific indicators for sport facilities, called “secondary”, are defined. These represent the measure of energy consumption per functional area and of local energy production/RES performance, that will be used as intelligent control parameters together with thermal comfort parameters.

Primary Indicators

Primary indicators are intended to be the measure of the whole building energy performance, considering the building as a “black box” where energy goes in through different carriers (e.g. electricity, gas, biomass etc.) and after the box it is delivered to utility needs (heating, cooling, equipment etc.). These indicators are normalized in order to provide a benchmark apart from the end-use and the location, so that a comparison with any kind of building is available. Table 1 is the list of identified primary indicators:

Table 1: Primary Indicators

Indicator Name	Symbol	Unit
Annual primary energy consumption	E_p	kWh_p/year
Annual delivered heating energy	$E_{h,del}$	kWh_h/year
Annual delivered cooling energy	$E_{c,del}$	kWh_c/year
Annual delivered electrical energy	$E_{el,del}$	kWh_{el}/year
Annual total gas consumption	G_{tot}	Nm^3/year
Annual water consumption	W	m^3/year
Carbon footprint	CO_2	kg/year
Annual energy cost	$€_{en}$	€/year

Each indicator becomes specific when referred to the total surface of the building or to the occupancy (e.g. Specific annual primary energy consumption is evaluated as kWh_p/m^2·year or kWh_p/user·year). Concerning primary energy, defined as energy that has not been subjected to any conversion or transformation process, Standard [15] describe the calculation with related coefficient to be used. [16] provides a description of how to reach the carbon footprint at European level. In particular three tables are reported with CO_2-production coefficient for electricity, local production and RES considering two standards: IPCC (International Panel on Climate Change) and LCA (Life Cycle Assessment). These standard indicators are not used for real-time control, but to measure and display global performances, also evaluated in shorter periods (e.g. a week or a day).

Secondary Indicators

Secondary indicators, unlike primary, are here intended to be specific for sport building. They provide a performance measure to compare different facilities used for the same function. Solving this issue means reaching two main features: indicators subdivision by functional areas and normalization factors enabling the comparison between equal facilities working under different conditions (location, weather, structure, plants etc.). Moreover these indicators take into account local energy production, including RES. The information of which energy is being used provides an instrument for use-profile management and resources optimization. EPLabel [17] project defined a methodology for buildings energy benchmark and in particular suggested the breakdown analysis by functional areas.

Table 2: Secondary Indicators

Indicator Name	Symbol	Unit
Solar thermal share of energy	S_{sol}	%
Biomass boiler efficiency	$\bullet_{bio}$	%
Cogeneration electric efficiency	$\bullet_{cog,el}$	%
Cogeneration thermal efficiency	$\bullet_{cog,th}$	%
Boiler efficiency	$\bullet_{boiler}$	%
Photovoltaic share of energy	S_{pv}	%
Lighting	L	kWh/m^2
Swimming pool thermal consumption	$Q_{t,pool}$	kWh/m^3_{pool} or kWh/user
Swimming pool electric consumption	$E_{t,pool}$	kWh/m^3_{pool} or kWh/user
Area thermal consumption	$Q_{t,area}$	kWh/m^3_{area} or kWh/user
Area electric consumption	$E_{t,area}$	kWh/m^3_{area} or kWh/user
Ext court electric consumption	E_{t,ext_court}	$kWh/m^2_{ext\_court}$

Ext service electric consumption	E_{t, ext_serv}	$kWh/m^2_{ext\_serv}$
Comfort	PMV_{area}	adimensional

The Area is the selected functional area (e.g. gym, fitness room, changing room, office etc.)
The share of energy is used for renewables and it is the ratio between production and load.

As shown in Table 2 indicators of functional areas can be normalized considering the volume: this choice is related to the fact that sport building structures are usually large and high, so that energy consumption is strictly related to the volume of treated air. Also illumination is proportional to the dimension of the space. A different normalization is required for the pool halls. In this case the higher energy consumption regards water heating, and in particular case fossil fuels for heating and electricity for pumping. A previous study, reported in [17], demonstrates that an indicator for swimming pools should consider the pool dimension instead of the hall dimension. The normalization factor used here is the volume of water of the pool that constitutes the major contribution to the heating energy consumption for such a facility. An additional normalization useful to make a benchmark between functional areas is the occupancy, so each indicator becomes specific when divided by the number of users. These indicators are powerful because, in addition to consumption data, they provide high-level information about the generation /usage profile, that can be used for optimization. Finally, the PMV thermal comfort indicator has been specifically added here: this parameter, discussed in the following Paragraph, is important to understand the thermal comfort inside the area especially when compared with the energy needed to achieve it.

Comfort Indicators

Thermal Comfort in Sport Facilities

According to ISO 7730 [18] a person feels comfortable when the air temperature, air movement, humidity and wall temperatures are in a balanced ratio to their activity and clothing. A person feels uncomfortable when the body's temperature-regulating system (the skin) is subject to stress and concentrations of heat or heat losses occur in the body. However, as the definition given in ISO 7730 implies, thermal comfort is a subjective sensation and it can be expressed with mathematical model function of PMV that takes into accounts body's parameters in relation with its surrounding environment:

(1) $$PMV = f(T, RH, v, MRT, clo, met)$$

where T [°C] is the room air temperature, RH [%] is the relative humidity, v [m/s] is the air velocity, MRT [°C] is the mean radiant temperature, clo [clo] is the clothing value, and met [met] is the metabolic rate. A typical temperature control loop does not take into account PMV and/or above related parameters. The PMV index predicts the mean value of the votes of a large group of persons with a 7-point thermal sensation scale (from -3, cold, to +3, hot). The PMV gives the mean value of the "thermal" votes of a large group of people exposed to the same environment. However, individual votes are scattered around this mean value and it is useful to predict the number of people likely to feel uncomfortably cold or warm (i.e. dissatisfied). This is what the PPD index is aimed for and it is expressed as function of the PMV:

(2) $$PPD = 100 - 95 \times e^{-(0.03353 \times PMV^4 + 0.2179 \times PMV^2)}$$

Procedures to evaluate or measure the parameters required in agreement to ISO 7730 are well known [19]. Some data are dynamic others static. This paper presents how to apply this procedure to typical functional areas inside a sport facilities through the definition of sets of static data based on type of activity carried out in each area and seasonal types of clothing, and through the definition of the measurement requirements of dynamic data acquisition. Some parameters are indirect and can be derived from empiric relations using both static and dynamic data. Standard [20] provides a procedure to evaluate clothing insulation with exhaustive tables of I_{cl} [m^2KW^{-1}] values for several clothing types. On its basis the clothing area surface factor f_{cl} is calculated. Man's metabolic rate (M) and external work (W) performed can be retrieved from standard [22], which contains the necessary data for calculation of M and W with tables for different physical activities. Measurement of the thermal environment parameters should be evaluated throughout the occupied zone, 0.6 m for a seated person and 1.1 m for a standing person. In this zone air velocity and air temperature should be recorded for a period of 3 minutes with a sampling rate of 5 Hz, air humidity (*RH*) with a sampling rate of 30 s. At the same level the mean radiant temperature (t_r) has to be evaluated. It can be directly measured using a globe thermometer (which is clearly not feasible for real-time control and has uncertainty up to ± 5°C [12][21]), or evaluated with an indirect method. Stated that for large spaces like sport buildings punctual accuracy is useless, a simplified method is preferable, as proposed by [23]:

(3) $t_r \approx t_s = t_a - R_i \cdot U \cdot (t_a - t_{ext})$

where t_a is the indoor air temperature, t_{ext} is the outdoor temperature, t_s the indoor surface temperature of the walls, R_i is the indoor heat resistance at the walls [$m^2 \cdot K \cdot W^{-1}$] and U is the mean heat conductance of the walls [$W \cdot m^{-2} \cdot K^{-1}$]. Room thermostats control based on single-point measurements may be significantly inaccurate when buildings with large non-compartmented volumes are considered. However measurements shall be tentatively performed in occupied zones of the building at locations where the occupants are known to or are expected to spend their time. Measurements should be taken at a representative sample of occupant locations spread throughout the occupied zone. In the case of exterior walls with windows, the measurement location should be 1.0 m inward from the centre of the largest window.

In order to evaluate of the water pressure p_a, following expression can be used:

(4) $p_a = 0.001 \cdot RH \cdot p_s$

where $p_s = 100 \cdot \exp(18.956 - \frac{4030.18}{t_a + 235})$ [kPa], is the water vapour saturation at the air temperature t_a. As shown, p_a is evaluated through humidity and temperature. Generally p_a influences the evaporative heat loss from person, thus the body energy balance. Usually a 10 % higher relative humidity is felt to be as warm as a 0.3 °C rise in operative temperature. However, humidity can have a significant influence in sport facilities in which higher values of air temperature and activity level together with transient condition can usually occur.

Table 3: Needed data for thermal comfort evaluation

Parameter	Type	Method
M Metabolic rate (W/m^2)	Static by functional area	Direct (ISO tables)
W external work (W/m^2)	Static by functional area	Direct (ISO tables)
f_{cl} clothing surface area factor	Static	Indirect
I_{cl} clothing insulation (m^2K/W)	Static by functional area	Direct (ISO tables)
t_{cl} clothing temperature (°C)	Dynamic	Indirect
h_c convective transfer coefficient ($W/(m^2$ K)	Dynamic	Indirect
v_{air} air velocity (m/s)	Dynamic	Direct (measurement)
t_a air temperature (°C)	Dynamic	Direct (measurement)
t_r mean radiant temperature (°C)	Dynamic	Indirect
RH (%)	Dynamic	Direct (measurement)
p_a water vapour partial pressure(kPa)	Dynamic	Indirect
p_s water vapour saturation(kPa)	Dynamic	Indirect
t_{ext} outdoor temperature (°C)	Dynamic	Direct (measurement)

Indices for long-term evaluation of comfort condition

ISO 7730 suggests more than one method for long-term evaluation of thermal comfort. Two of these are here chosen as the most appropriate performance indicators for a better control in sport facilities. The Method A calculates the number or percentage of hours, out of the occupied building hours, the

PMV is outside a specified range. Applying this method to sport facilities requires that a comfort range per each functional area has to be defined, due to different tolerances regarding the thermal environment. Obviously in this way the out-of-range is an absolute value, so differences between negative (cold) and positive (hot) values are not taken into account. The Method C estimates the time during which actual PMV exceeds the thermal comfort boundaries, weighted with a factor which is a function of the PPD:

1. The weighting factor, w_f, equals 1 for $PMV=PMV_{limit}$, where PMV_{limit} is determined by the comfort range calculated for the considered sport functional area
2. The weighting factor w_f is calculated as $w_f = \frac{PPD_{actualPMV}}{PPD_{PMV\text{limit}}}$ for $|PMV|>|PMV_{limit}|$
3. Considering a characteristic period during a year, the product of the weighting factor and the time t, is summed and the result expressed in hours:

Warm period is $\sum w_f \cdot t$ for $PMV>PMV_{limit}$ and Cold period is $\sum w_f \cdot t$ for $PMV<PMV_{limit}$.
Both methods provide a comfort parameter that can be used as indicators of the comfort level inside the functional areas to be real-time displayed in the smart metering interface and also as feedback for HVAC system control.

Set of parameters dedicated for sport areas

Sport facilities are peculiar buildings because they are heterogeneous in types of activity and occupancy. Occupancy, together with weather, are the common independent variables defined as characteristics of a facility's use having an impact on energy consumption. Weather is most often just outdoor temperature and possibly humidity. Occupancy may be defined as whole facility occupancy factor, functional area occupancy hours or maximum hours, number of occupied days. The definition of occupancy to be applied depends on presence of the detailed access control installed in the considered Sport facility. Independent variables should be measured and recorded at the same time as the energy meters. In the following a set of static parameters for comfort evaluation is proposed, considering the different aspects of activity and of occupancy for the different functional areas.

Swimming Pool

Recent studies [10] analyses the influence of space temperature on wet swimmers out of the pool through the PMV calculation method. Authors applied the following parameters:

Table 4: Comfort parameters for wet swimmers in swimming pools as used in [10]

Static Data		**Dynamic Data**
M= 70 W/m^2	v_{air}= 0.1 m/s	t_a air temperature °C
W= 0 W/m^2	h_c= 12.1·v$^{0.5}$ W/m^{2}K	t_{ext} outdoor temperature °C
f_{cl}=1	t_{cl}= 33.74 °C	$t_r = 0.92 \cdot t_a + 0.085 \cdot t_{ext}$ (eq. 3)
I_{cl}=0 m^{2}K/W		*RH* indoor humidity

As an application example, in order to reduce energy consumption maintaining the adequate comfort level, in spring, autumn and winter condition, the air temperature can be set on the lower limits of temperature range of thermal comfort (PMV= • 0.5). On summer day, air conditioning is needed to eliminate indoor heat and moisture gain, and the indoor space temperature can be set at the upper limit of temperature range (PMV= 0.5) to save operation cost. Static and dynamic data of Table 4 are here extended to other typical pool user types as follows:

Table 5: Parameters usable for generic swimming pools

Static Data	**Dynamic Data**
M metabolic rate (W/m^2)	t_a air temperature (°C)

	t_{ext} outdoor temperature (°C)
	$t_r = t_a - R_i \cdot U \cdot (t_a - t_{ext})$ mean radiant temperature (°C)
	$h_c = 12.1 \cdot v^{0.5}$ convective heat transfer coefficient (W/m2K)
Clo clothing insulation (m^2K/W) Dry swimmer 0 clo Bath superintendent 0.4 clo Spectators 0.6 clo	v_{air} relative air velocity (m/s) *RH* indoor humidity (%)
Note: R_i=indoor heat resistance at the walls (m^2K/W), U=mean U-value of the walls (W/m^2K)	

Fitness – weight machines room

In fitness area the following range of parameters extracted from [24] can be considered according to the typical activities practiced:

Table 6: Metabolic rates for typical sport activities

Activity	Met units	W/m^2
Dancing	2.4 – 4.4	140 – 225
Calisthenics/exercise	3.0 – 4.0	175 – 235
Tennis, single	3.6 – 4.0	210 – 270
Basketball	5.0 – 7.6	290 – 440
Wrestling, competitive	7.0 – 8.7	410 - 505

On the other side, the thermal insulation of characteristic clothing used inside these area has to be taken into account as well as the sweating due to the sport activity. In this case standard ISO 9920 [20], further than a calculation procedure and tables of values for each type of garment, provides clothing factors for a typical “athletic sweat suit” with f_{cl} = 1.19 and I_{cl}= 0.115 m^2K/W.

Changing Room

This area can be considered similar to a swimming pool, since occupiers are wet and naked. That gives good reason to use data showed in Table 4 Table 5.

Support/administrative area

Usage of these areas is closely similar to office. It means that metabolic activity is 70 W/m^2 (1.2 met) as reported in ISO 7730, while clothing factors can be retrieved from the same standard. In this case seasonal parameters are to be considered regarding the clothing.

Complete monitoring system for a swimming pool

Measurement of energy consumption

Swimming pools consume more energy than other sport areas because of their complexity due to water treatment and interaction air/water surface, so a pool is here chosen as a case study. Monitoring a pool requires measuring how much energy is used for water heating/pumping, air heating/cooling, ventilation, lighting and equipment. Thermal and electrical consumptions have to be monitored (according to Table 2) for performance evaluation, trying to have a measurement system as much as possible independent from the type of energy supply/generation/distribution system and energy carriers. Here it is explained how to reach this objective considering which quantities are to be measured and relative measurement locations. Figure 1 shows a scheme of a swimming pool plant with suggested measurement points. Heat meters measure both temperature differences and flow rates. If breakdown is unneeded, total electrical and thermal consumption can be retrieved from meters E1, H1, H2 and H3. In any case sub-metering allows an accurate analysis in order to reach accurate energy figures that are needed for a correct data normalization (e.g. weather correction as explained in the next section).

Table 7: Measurements points for energy breakdown related to Figure 1

Target	Thermal Consumption	Electrical Consumption
Water Treatment	H1, H3	E6
Air Heating/Cooling	H2	E2, E3
Ventilation		E4
Lighting		E5
Equipment		E7
Total	H1, H2, H3	E1

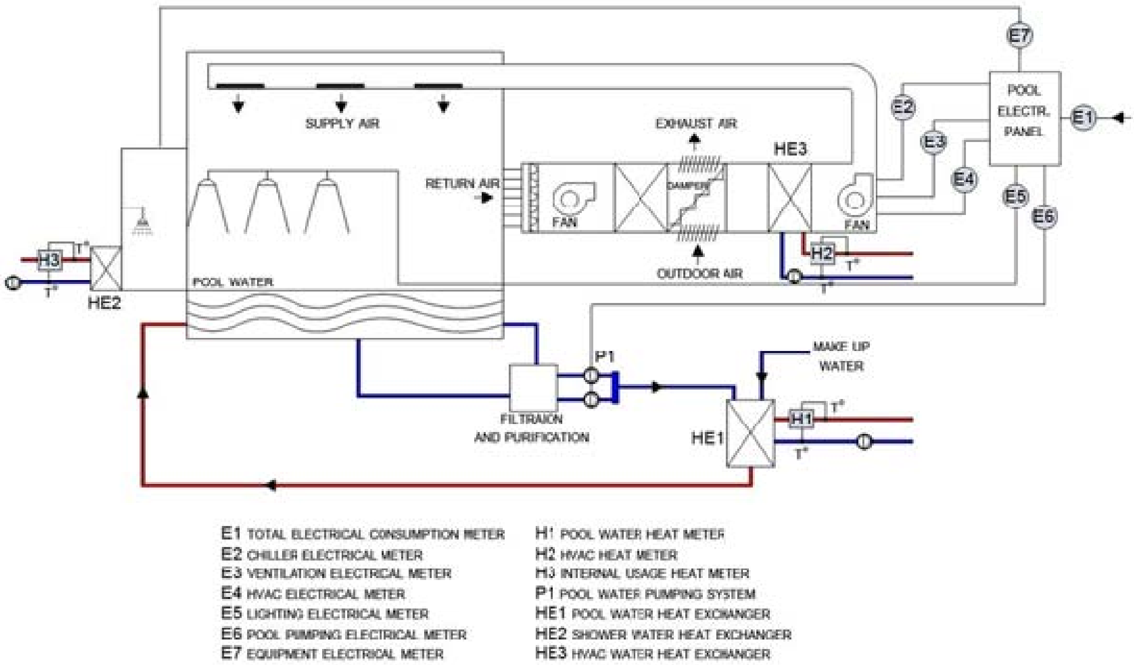


Figure 1: Scheme of a swimming pool plant with measurement points

Normalization of measured data

The described measurement system allows the knowledge of how much energy is consumed for heating. However, energy consumption tends to depend on the outside air temperature. A weather normalization allows the adjustment of energy-consumption data to factor out the variations in outside conditions. Weather normalization is commonly used when analyzing changes in a building's energy consumption, and, when combined with other normalization techniques (such as normalizing for occupancy and building size using the “specific” indicators as explained above), when comparing the energy consumption of different buildings. “Degree-day” is essentially a simplified measure of historical weather data (outside air temperature data to be specific). Normalization for heating energy is commonly applied using the heating degree-day (HDD) method, but normalization for cooling energy is not widely used and in particular cooling degree-days (CDD) because it does not take into account of the solar gains. Higher frequency of outdoor temperature measurement (e.g. 30 minutes), allows higher accuracy in HDD calculation. However EN ISO 15927-6 [25] provides a solid standardized method to evaluate HDD:

(5) $G = \sum_{period} (t_{base} - t_{out})$ for $t_{out} < t_{thr}$

where t_{out} is the daily average outdoor temperature during one heating day available from continuous measurements, t_{base} is the base temperature, which is the temperature that the heating plant is assumed to provide and t_{thr} is the threshold temperature, which is the outdoor temperature at which the heating plant is turned on/off.

(6) $E_{h,corr} = E_{h,meas} \cdot \frac{G_m}{G}$

where is $E_{h,corr}$ [kWh/year] is the corrected heating energy consumption, $E_{h,meas}$ [kWh/year] is the measured value of heating energy consumption, G [K·d] is the degree days evaluated using equation 5, and G_m [K·d] is the long-term average of annual degree days. G_m is generally provided by standards in each Country with a base temperature related to typical office or home buildings (e.g. 15 °C) and not to typical sport areas. In detail each type of area has a different set point and internal load due to the activity performed, so that it is impossible to find a common base temperature t_{base} for the whole building. This is one of the reason of the breakdown analysis presented in this paper. Moreover because of this lack of standardized long-term average of annual degree days a dedicated calculation is needed to apply this methodology. The proposed idea is to define a reference year as baseline (e.g. the last year before the installation of the monitoring system) and to use the data of the nearest weather station to calculate degree-days for normalizing the energy consumption of that year. After the installation of the monitoring system the base load typical of the building is identified and then the specific energy consumption of the base year can be corrected. Finally, as said above, the set-point for internal temperature varies area-by-area, in fact for a swimming pool the base temperature might be more correctly around 26°C, rather than 15°C. A method to evaluate the appropriate base temperature is proposed in [26], where correlation between energy consumption and degree day by regression analysis is performed.

Simulation of measurement of comfort conditions

In order to asses feasibility of the proposed monitoring approach, typical PMV/PPD data have been simulated. The aim here is to highlight the information achievable for the smart monitoring system and example of following decision taking procedures. A simulation model of a swimming pool is used to model the internal condition and the needed parameters. Lumped parameters modeling of the building is performed using HAMBase [27] integrated with the model of a swimming pool and of the HVAC system in Simulink Environment.

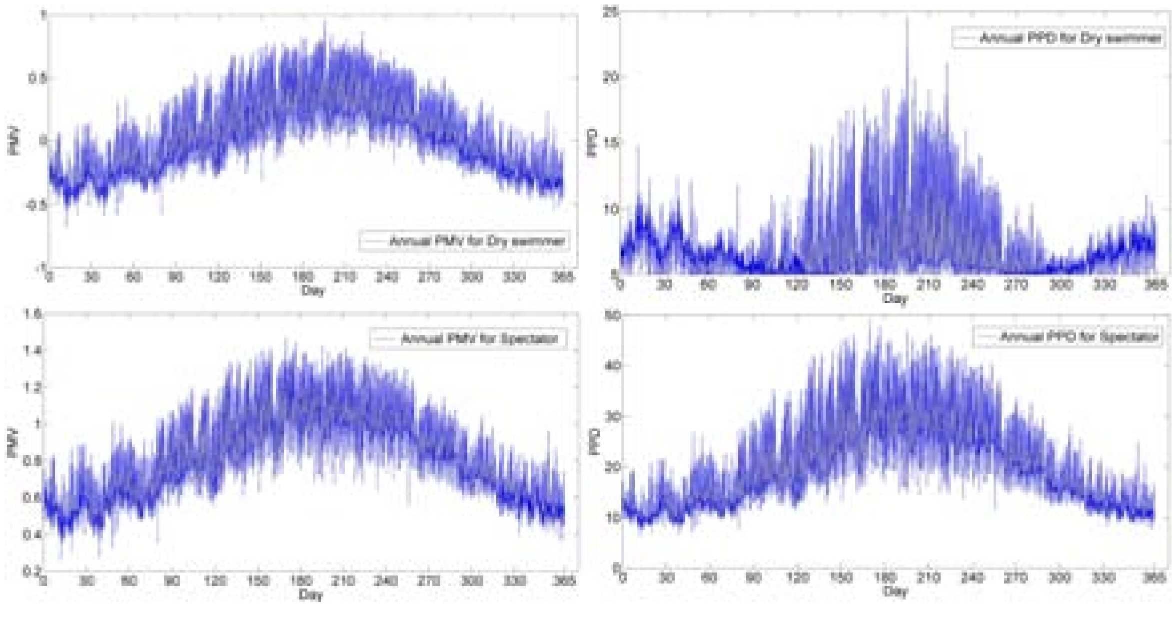


Figure 2: Annual profiles of PMV and PPD for a dry swimmer and a spectator in a swimming pool

Then comfort indices PMV/PPD are evaluated using the methodology described in the above sections. In particular two profiles of the Table 5 are used, “Dry swimmer” and “Spectator”, using simulated data covering one year. Results clearly show how the thermal comfort is a sensation subjected to the type of activity and clothing, as expected. In detail the conducted analysis aims at evaluating the thermal condition of different persons in the same ambient where sport activities are performed, given a certain HVAC regulation and outdoor temperature. This is crucial in sport facilities to apply more efficient control strategies maintaining the well-being of the occupants. PMV and PPD for spectators (Figure 2) are always higher than indices calculated for swimmers with a major number of unsatisfied spectators. Based on similar data, the manager can take decision on the regulation. For example, using “swimmer” profile, the comfort indicator (Method C) is evaluated considering the occupied hours during which PMV is out of the range ± 0.5 and plotted as shown in Figure 3. This data analysis highlights a limited number of cold hours, so that a reduction of the heating load can be considered as acceptable to achieve a better comfort condition for spectators together with a significant energy saving.

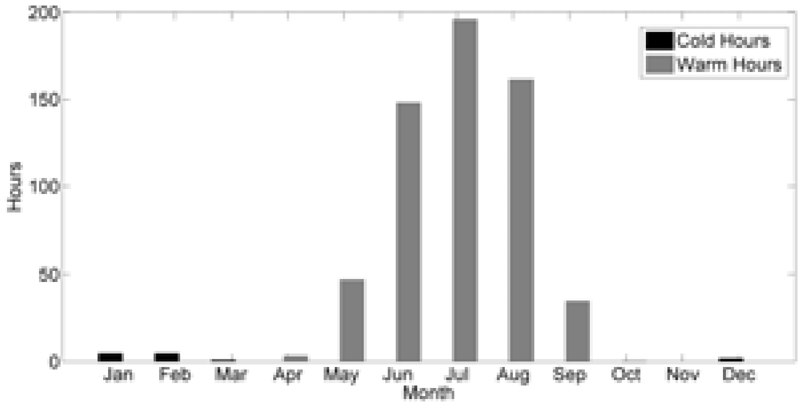


Figure 3: Warm/Cold hours for Dry Swimmers profile using Method C of ISO 7730

However, some relevant considerations have to be done on the measurement methods and required accuracy. In [28] PMV sensors based on open networking technology were developed, but a high uncertainty (±0.6) was found. A detailed analysis on the sensitivity of PMV index to the physical parameters measurement accuracy has been recently performed in [21], showing that, even if measurements are performed within the accuracy requirements proposed by ISO 7726, the PMV can easily be so uncertain (±0.2 - 0.3) to make the classification of the environment quite random. In particular, the highest sensitivity is related to the accuracy in the measurement of the mean radiant temperatures (t_r), which is the most critical also due to limited accuracy of available measurement systems. However it is also noticed that PMV uncertainty dramatically decreases if the measurement of this quantity is carried out within the desired accuracy requirements. For this reasons authors have recently developed a new alternative method for continuous PMV measurement [29]. The sensitivity analysis in [21] also showed that for high metabolic rates, the sensitivity to measurement uncertainty decreases and becomes less significant in particular for t_a, v_a and p_a. These information improve applicability in sport facilities and can be used to practically implement the proposed metering system. In addition it has to be considered that swimming pools or other typical sport halls are usually large spaces subjected to air stratification or air temperature gradients due to the disposition and exposition. Sensors number and positioning should be optimized keeping into account these factors. A dedicated analysis is therefore under development by the authors in order to provide a method for sensors position optimization minimizing impact of the measurement accuracy on real-time comfort evaluation in sport facilities.

Conclusion

This paper presents the design of a monitoring system combining measurements for both energy and comfort variables in a dedicated approach for sport and recreational facilities. The basic idea of the present approach is that the environment of sport facilities should be managed and controlled not only to save energy and costs, but also to maximize people comfort in all the different functional areas. Firstly the paper provides a formulation of metrics useful for sport facilities benchmarking. Stated that sport buildings are heterogeneous, a list of universal primary and secondary indicators (including comfort indices) are defined that can be used for multiple compositions of functional areas and subsystems located in different climate conditions. Methods to estimate parameters for PMV measurements in different sport areas are defined. It is shown that particular attention has to be dedicated to the data normalization in order to have a neutral benchmark of the building performance under different conditions. The described approach is adaptable to both new and existing facilities, indoor and outdoor areas, different types of functional areas and for systems embedding RES. Obviously general methodology and criteria are proposed, but the implementation is case-by-case because of the wide range of possible configurations (plants, distribution, etc.).

Then an example of the method applied to a swimming pool is developed, discussing how to practically measure the required quantities. A pool lumped parameter model is used to simulate comfort data. It is shown that PMV/PPD indices can be used to evaluate the real thermal feeling experienced by pool users and to take informed management decision for energy saving. The evaluation of these indices requires a set of static parameters function of the typical activity performed in sport areas, here defined, but also a set of quantities to be dynamically measured with a required accuracy, with consequent increase of the monitoring system costs. Given the critical sensitivity of PMV estimation to measurement uncertainty (in particular for the mean radiant temperatures) and the relevant air stratification in these facilities, problems related to the effective implementation of the sensor network for PMV measurement have to be further analyzed. As a consequence, the authors are now developing a study to find the optimal sensor position/number in order to reduce the uncertainty related to these measurements in large sport areas, which will be followed by an extensive full scale calibration and demonstration of the method.

Acknowledgments

This research is partly funded by the EU SPORTE^2 ((Intelligent Management System to integrate and control energy generation, consumption and exchange for European Sport and Recreation Buildings) project (www.sporte2.eu) under the 7FP (ICT Programme, Grant agreement no: 260124). The authors wish to thanks the partners for the useful discussions.

References

[1] Government’s Energy Efficiency Best Practice Programme. *Energy use in sports and recreation buildings*, London, 2001. Can be downloaded at: http://www.targ.co.uk/other/guide78.pdf

[2] Sullivan G.P. and Pugh R. *Metering Best Practice.* U.S. Department of Energy, Federal Energy Management Program, 2011. Can be downloaded at: http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf

[3] DOE. *Guidance for electrical metering in federal buildings.* Federal Energy Management Program, 2006. Can be downloaded at: http://www1.eere.energy.gov/femp/pdfs/adv_metering.pdf

[4] Genet J.P and Schubert C. *Designing a metering system for small and medium-sized buildings,* 2011. SEMED310007EN.

[5] CIBSE. *GIL65 Metering energy use in new non-domestic buildings,* 2002.

[6] Hwang R., Lin T.P., Liang H.H., Yang K.H. and Yeh T.C. *Additive model for thermal comfort generated by matrix experiment using orthogonal array.* Building and Environment, 2009, Vol. 44 pp.1730-1739.

[7] Kang D.H. *Effect of MRT variation on the energy consumption in a PMV-controlled office*. Building and Environment, 2010, Vol. 45 pp. 1914-1922.

[8] Tse W.L. and So A.T.P. *Implementation of comfort-based air-handling unit control algorithms.* ASHRAE Winter Meeting (Dallas, US, 5-9 February 2000). ISSN 0001-2505.

[9] Hwang R. and Shu S. *Buildings envelope regulations on thermal comfort in glass façade buildings and energy-saving potential for PMV-based comfort control.* Building and Environment, 2011, Vol. 46, pp. 824-834.

[10] Sun P., Wu J.Y., Wang R.Z. and Xu Y.X. *Analysis of indoor environmental conditions and heat pump energy supply systems in indoor swimming pools.* Energy and Buildings, 2011, Vol. 43 pp. 1071-1080.

[11] Rajagopalan P. and Eldaki H. *Thermal and ventilation performance of a multi-functional sports hall within an aquatic centre.* Proc. of the 12th Conference of International Building Performance Simulation Association (Sydney, Australia, 14-16 November 2011).

[12] ISO. 7726:2002. *Ergonomics of the thermal environment. Instruments for measuring physical quantities,* 2002. ICS 13.180

[13] Kumar A., Singh I.P. and Sud S.K. *Thermal comfort feelings assessment based on digital signal processor.* International Journal of recent Trends in Engineering, 2009, Vol. 1.

[14] Kumar A., Singh I.P. and Sud S.K. *An approach towards development of PMV based thermal comfort smart sensor.* International Journal on Smart Sensing and Intelligent Systems, 2010, Vol. 3.

[15] EN 15603:2008. *Energy performance of buildings. Overall energy use and definition of energy ratings,* 2008. ISBN 978-0-580-59028-3

[16] Covenant of Mayors. *How to develop a sustainable energy action plan,* 2010.

[17] http://www.eplabel.org/

[18] ISO. *ISO7730:2005 Ergonomics of the thermal environment—Analytical determination and interpretation of the thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria,* 2005. ICS 13.180.

[19] Markov D. *Practical evaluation of thermal comfort parameter.* Annual International Course. Ventilation and Indoor climate, Sofia, 2002.

[20] ISO. *ISO9920:2007 Ergonomics of the thermal environment – Estimation of thermal insulation and water vapour resistance of a clothing ensemble,* 2007. ICS 61.020.

[21] Alfano F., Palella B.I. and Riccio G. *The role of measurement accuracy on the thermal environment assessment by means of PMV index.* Building and Environment, 2011, Vol. 46, pp. 1361-1369.

[22] ISO. *ISO8996:2004 Ergonomics of the thermal environment – Determination of metabolic rate,* 2004. ICS 13.180.

[23] Lammers J. *Human Factors, energy conservation and design practice.* Doctoral dissertation Technische Universiteit Eindhoven, 1978.

[24] ASHRAE. *55:2010 Thermal Environmental Condition for Human Occupancy,* 2010.

[25] ISO. ISO 15927-6:2007 *Hygrothermal performance of buildings. Calculation and presentation of climatic data. Part 6: Accumulated temperature differences (degree-days).* 2007. ICS 07.060.

[26] CIBSE. *TM41:2006 Degree-days: theory and application*, 2006. ISBN 1-903287-76-6.

[27] Wit M.H. *HAMBase, heat, air and moisture model for building and systems evaluation.* Eindhoven University of Technology, 2006. ISBN 90-6814-601-7.

[28] Tse W.L. and Chan W.L. *Real-time measurement of thermal comfort by using an open networking technology.* Measurement, 2007, Vol. 40, pp. 654-664.

[29] Revel G.M., Sabbatini E. and Arnesano M. *Development and experimental evaluation of a thermography measurement system for real-time monitoring of comfort and heat rate exchange in the built environment.* Measurement Science and Technology, 2012. Doi 10.1088/0957-0233/23/3/035005.

Improving energy efficiency in commercial buildings at the use stage: an achievable objective

Guillermo Escrivá-Escrivá

Institute for Energy Engineering, Universitat Politècnica de València

Abstract

Numerous studies have focused on improving energy efficiency in commercial buildings. Engineers and researchers have developed complex methods to improve energy efficiency, but buildings are often managed by non-specialised technicians who need require easy, clear and low-cost actions to implement in their buildings. This paper presents basic actions on which to base improvements in energy efficiency at the use stage in commercial buildings. Furthermore, obtained results and details of the implementation of these actions in various buildings in the Universitat Politècnica de València are presented.

Keywords: energy efficiency; use stage, basic actions, commercial buildings

1 Introduction

Energy consumption has recently become a major issue because of growing concern about CO_2 and other greenhouse gas emissions and the scarceness of fossil fuels [1]. Improvements in energy efficiency are crucial to reduce emissions and protect the environment [2].

Energy behaviour characterisation and quantification is the first step towards the identification of actions to improve energy use [3, 4].

Commercial (non-industrial) buildings are one of the biggest consumers of energy accounting for 30-40% of the total primary energy consumed in developed countries, and this consumption is increasing [5].

The energy behaviour of these types of buildings has received a great deal of attention in Europe, and has been the subject of a specific European Directive (2002/91/CE) [6]. This recast directive states that building energy demand depends on building construction quality, location, orientation, climatology, and the efficiency of the energy systems deployed in the building. Reference energy consumptions are used for evaluation purposes.

The construction phase is the basis for an optimum consumption in buildings. Proper insulation, orientation, materials, design of facilities, etc., directly determine the energy consumption of buildings. But these measures do not ensure an efficient consumption at the use stage. During the use stage it is the management of the building and equipment used in it – together with the above factors – that really determines energy consumption [7].

Energy market prices and contract terms must also be considered in the management of a building because managers want low-cost efficient use of energy. Demand response actions (changes in consumption in response to price signals, incentives, or directions from grid operators) may also be significant when managing a building because these actions may influence energy cost but smaller financial impact (e.g. shifting energy consumption to valley periods) [8-11].

Use of renewable energy sources [12] and replacement of existing equipment with more efficient equipment [13, 15] are common solutions for energy efficiency improvement, but require a significant investment and long pay-back periods. By contrast, this paper deals with simple and inexpensive management actions that can be performed in existing buildings.

The methods by which buildings are managed significantly affect energy consumption during the use stage. Engineers or other less qualified technicians are usually responsible for the management of buildings and require easy, clear and low-cost instructions to improve energy use. This paper proposes actions to enable a correct energy use in buildings and achieve a better use of energy without the need for time-consuming tasks or expensive measures to achieve these goals.

The paper is organised as follows. Section 2 describes the general parameters to be considered to improve energy efficiency. Section 3 presents the actions proposed to improve energy efficiency. In Section 4, results are presented when applying the proposed techniques to various buildings in the Universitat Politècnica de València (UPV). Finally, some conclusions are drawn in Section 5.

2 Building consumption parameters

For a specific constructed building (in a particular climatology, orientation, etc.) several parameters have to be taken into account for a building energy analysis [3]. The parameters for energy evaluation to determine building energy consumption in UPV buildings are:

Dimensional parameters:

• Building space. The area included within the external wall of the building, excluding outdoor space (terraces, etc.) or external access areas (stairs, elevators, etc.)

• Air-conditioned volume. Total volume of each enclosed area in a building that is air-conditioned.

• Wall internal distribution. Layout of the building considering size and type of corridors, common areas, offices, toilets, stairs, halls, etc.

Building characteristics:

• Building types. It is important to define the use of each building area (classrooms, offices, research labs, computer labs, halls, cold-storage rooms, etc.) because this determines the energy requirements. Once the use of each area is defined, it is possible to define the general use of the building.

• Hours of use. Energy demand depends on hours of utilisation. Holidays and work calendars are considered. It is important to identify holiday periods because during these times buildings are closed and consumption is lower than usual.

• Number of users. Each building has its characteristic total number of users which is determined by analysing each specific area and the percentage of users for each hour.

• Type of air-conditioning. There are two common types of heating, ventilation, and air-conditioning (HVAC) systems: centralised or individual (split systems). Actions to improve energy efficiency in HVAC systems are also presented in this paper.

3 Proposed actions

This paper deals with the basic actions that have to be considered when trying to achieve a reduction in energy consumption during the use stage in commercial buildings. The author presents the general ideas to be implemented to achieve an optimal management. These actions are summarised in Table 1 and are explained in detail in the following sections.

Table 1. Seven basic actions to improve energy efficiency.

No.	Action	Description	Application
1	Energy consumption measurements and data storage	Accurate and automatic data acquisition	- Detect over-consumption - Assess energy savings
2	Schedule different processes	Establish a diary of utilisation by paying attention to the electric current contract	- Utilisation of the facilities adapted to the requirements of users
3	Automatic monitoring of energy consumption	Automatic system that alerts building managers when consumption increases	- Manager focuses on repair or solving malfunctions
4	Individual in charge of consumption	Somebody is assigned responsibility for consumption	- Energy consumption will always be considered
5	Pro-active actions to decrease consumption	Remote control actions enable managers to reduce consumption	- Proper management of the premises
6	Modify premises for an easier management and lower consumption	Modify control buttons and installations of electrical panels for a better understanding and control by building users	- Clear and precise control panels - Adapt control buttons to actual use
7	Communication between manager and users	A fixed place where managers and users can interact is necessary to have an optimal use of the facilities	- Facilitate the exchange of information between managers and users

3.1 Energy consumption measurements and data storage

Most of the present panels in buildings are already equipped with power meters. However, it is a major error not to save such data. Up to date technicians are using these measurements only to verify instantaneous consumption, but these measurements are useless if records are not kept. Consumption data must be stored in an easy access database for later analysis.

Therefore, accurate measurements and storage of energy consumption data is the most important action to be performed in order to improve building energy consumption.

The application developed to acquire data must store hourly energy consumption and alert managers when there are no measurements. When communication with a power meter is not possible, the information may be stored locally and when communication is restored the energy consumption data may be distributed for the period.

Power meters must be placed in the main-breaker to obtain the total consumption of the building and in all the other high consumption processes where improvements in energy efficiency are desired.

Storage of consumption data facilitates the calculation of costs and savings, the assignment of consumption to different processes, and the analysis of consumption in non-working periods.

3.2 Schedule different processes

A schedule of all planned activities is very important to properly manage the facilities of a building and enable the definition of user requirements. As energy in buildings is used to satisfy the user requirements, it is very important to define the moments and quantities of energy user requirements in each area of the building. Thereby, the definition of the opening and closing times in each building is crucial.

Energy contract terms must be considered when programming different processes in order to shift energy consumption to valley periods and avoid high consumption during price-peak periods if there is a capacity limit in the contract.

3.3 Automatic monitoring

The electrical consumption is not visible for the users or the manager of a building. It is therefore important that software tools are used by managers to save time when monitoring consumption in the controlled panels. An automatic monitoring of consumption enables verification of the energy consumption during a period and alerts the manager to any anomalous situations when consumption higher than a pre-fixed threshold is detected. Consequently, actions to return to the normal situation may be performed. Managers should receive an automatic alert when a malfunction is occurring in premises under their control. Furthermore, maintenance of the panels will be required if malfunctioning is constantly detected.

3.4 A responsible individual must be assigned

A responsible individual must be appointed in each building, or group of buildings, to monitor consumption. This person must also take necessary measures to ensure consumption remains as efficient as possible.

3.5 Perform pro-active actions to decrease consumption

Lighting circuits and HVAC systems should be remotely controlled in order to adapt their operating times to the requirements of the users and avoid wasting energy.

Maintenance of the correct functioning of the premises (HVAC system, lighting system, etc.) must be performed. After a malfunction in a system, due to any problem, the restoration of the system should be made to the point where the consumption threshold was defined.

To perform automatic control actions of the facilities, connections/disconnections in the different premises (HVAC, lighting system, power system, etc.) can be defined and overridden by an energy management and control system (EMCS), in which it is possible to store several schedules that take into account national holidays, local holidays, weekends, etc. The EMCS may be used to interact with all the other systems and facilitate the correct use of the facilities. This system can establish permission to use or not use certain facilities depending on different schedules, seasonal daylight, occupancy, etc. The controlled action must only force the non-operation of some devices in certain periods and users must be responsible for activating the devices, otherwise some devices may be connected for no purpose.

3.6 Modification of facilities to make management of systems easier

Control facilities are often used by non-technical people who are responsible for connecting and disconnecting devices, but really do not know how to connect or disconnect correctly. Therefore, it is necessary to modify premises so as to facilitate their use by non-technical staff leading to a decrease in energy consumption.

Construction phase errors or changes in the use of the systems require modification of the premises in order to accomplish an optimum use of the facilities.

Some examples of the modifications that can be performed in the facilities include: modify lighting system to adjust to new uses or areas; modify obsolete panels; install additional control buttons that enable an optimal use; and modify the HVAC control to ensure a lower consumption.

3.7 Communication between managers and users

Finally, a channel of communication between users and managers of buildings is required to adapt services (lightning, HVAC system, etc.) to the users and share information.

4 Results and implemented actions in the UPV

The above mentioned actions have been implemented at the UPV. The results of this trial are presented below. Seventy buildings have been controlled in the UPV through the Derd project for managing distributed energy resources and demand [16]. The goal of the Derd project is the implementation of new tools and techniques to facilitate the management of the various energy resources used in the existing infrastructures of the university; as well as improving energy efficiency and the control of distributed loads. Electrical consumption in the UPV costs more than €7m per year. Savings above €1.4m have been achieved using the above actions during four years of project implementation. Current annual saving reaches €500,000. Investment of €1.5m has been necessary as well as a manpower cost of €730,000. The total cost has been €2,230,000 and the pay-back period is 2.5 years [17]. The following sections provide details on the implementation at the UPV.

4.1 Energy consumption measurement and storage

At the UPV, the hourly consumption data shown below is obtained at two electrical points in each building: total consumption in the main breaker and total consumption in the HVAC system main panel.

Moreover, measurements in electrical transformer stations are also useful. The acquisition of consumption data in transformers is important for the following functions:

- Monitoring the load level of power transformers.

- Detecting when a transformer has been put into service.

- Detecting when a main breaker has tripped and another transformer is supplying the entire load (for parallel configurations).

In this work, these measurements are obtained using a flexible energy management and control system (EMCS) developed at the Institute for Energy Engineering (IIE) of the UPV [17].

The EMCS enables managers to measure energy consumption, store and manage data, control consumption, and ensure that power does not exceed a set point. All the information is gathered in the control centre where the main server and the SQL database are located. Data is formatted to store the information with partition of the data tables in the database, and also a proper storage of the hour and date (hh:mm: 00) is performed for a correct post-analysis. The EMCS architecture is shown in Figure 1.

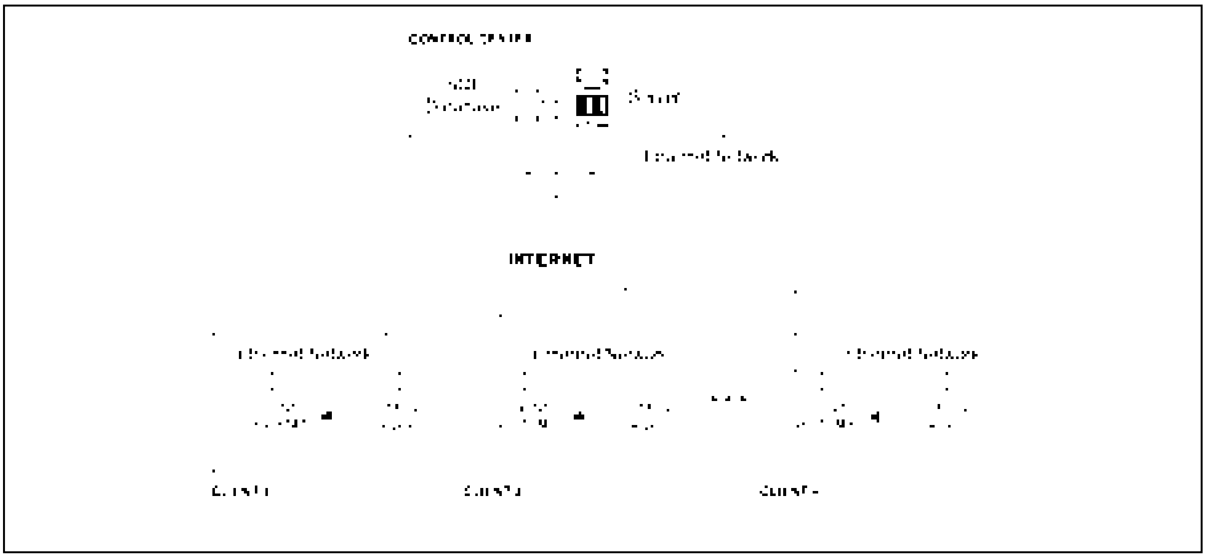


Figure 1. EMCS architecture developed in the UPV.

EMCS can obtain measurements from various types of equipment already installed in the UPV and daylight saving hour changes are taken into account.

The consumption of a combination of meters (the sum of two meters, subtraction, etc.) is also possible.

More than 250 power meters have been installed in the controlled buildings. The central server collects data every 15 minutes.

This method presents a major advantage when a loss of communication occurs between the server and meter. In such a case, the energy consumption is stored in the meter (which remains in operation) and so no data is lost. The software alerts (via email) the manager when a problem in communication occurs.

The power meters installed are PM710 meters by Telemecanique and 104 parameters are stored for each acquisition. All data can be read through a web interface from any point with an Ethernet connection [17-19].

4.2 Schedule different processes

Prefixed plans are defined for the buildings and facility schedules. This enables energy consumption to be adapted to user requirements and the terms of the energy contracts. Facilities must be in OFF mode when unused.

The UPV is currently under a six period energy contract. The transfer of loads to valley periods and the avoidance of unnecessary consumption in peak periods is therefore essential.

Figure 2 shows the effect of the schedule fixed through the EMCS on the controlled loads on a Saturday. Several HVAC devices are connected at 7:00 am and disconnections occur at 2.30 pm.

The utilisation of programmable logic controllers (PLCs) to control the premises and general management through a control system (the EMCS) are very useful for scheduling devices and also enable the automatic establishment of different timetables for holidays, weekends, etc. A local push button in the control panels is used to enable manual intervention by the building manager to locally overwrite the order given by the PLC in periods when the disconnection of the devices is not desired.

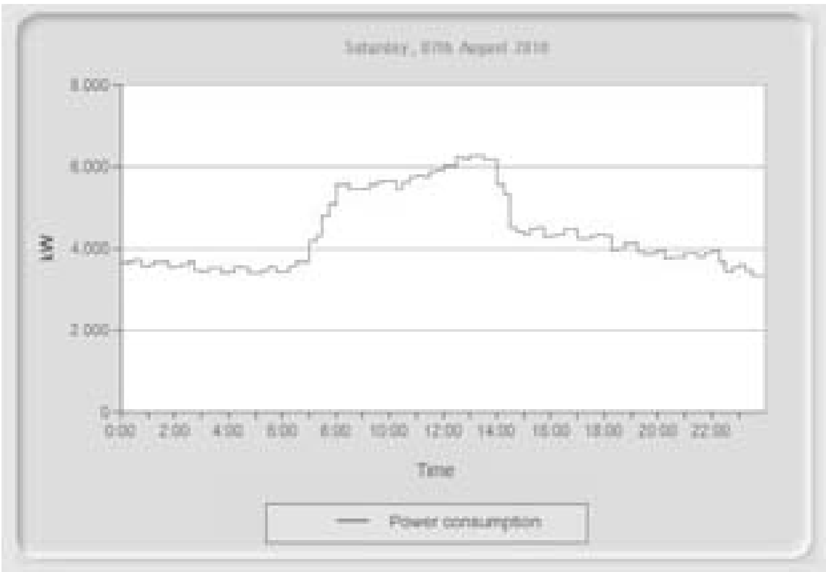


Figure 2. Result in total consumption at the UPV (aproximatelly 70 buildings) due to building scheduling

Timers must not be used to schedule the premises because memory is erased when a power cut occurs. Remote control is also required and this is very difficult to accomplish with these types of equipment.

4.3 Automatic energy consumption monitoring and individual responsible for consumption

In the UPV an application compares the consumption in each building daily with the corresponding prefixed threshold. A baseline calculation defines the threshold of consumption. External temperatures [20], day of the week, seasons, etc. are considered in the baseline forecast.

As mentioned, an individual must be assigned to be responsible for energy consumption in each building. In the UPV, an energy office has been created to manage, monitor, and report on energy consumption in all buildings.

4.4 Pro-active actions to decrease consumption

Pro-active actions to decrease consumption must be performed to lead the system to lower consumption and improve energy use [21]. Through the Derd project more than 2,500 controlled lines (HVAC devices, lighting circuits, extractors, etc.) have been controlled through the implemented EMCS. Controlled devices can be forced into OFF mode [19]. This system only needs to ensure that devices are switched off; it is the users who must switch devices on. Otherwise, the system would connect some devices unnecessarily. Most of the HVAC devices in the university have been connected to the EMCS and consumption can be controlled by adjusting the timetable for different loads. Furthermore, the EMCS website offers demand response program functions [8, 11]. These functions enable customers to respond to price signals and so obtain profits.

More than 3,200 actions, connections, and disconnections are performed by the system each day.

Common actions usually performed in the UPV include:

- Readjustment of existing timers and PLCs. Some models lose their storage schedules when there is a power outage.

- Lights left on at night may be detected during an annual night-time inspection.

- Several actions in the HVAC systems can be performed to produce significant savings. This is due to the high rate of consumption by HVACs in commercial buildings (30-40% of the total consumption [5, 16]) and the flexibility due to the inertia of a thermal system. Different actions are performed depending on the type of HVAC system. Splits are controlled through a contactor installed in the switching circuit. VRV systems are switched off using a pulse signal in an additional remote control that forces all the interior units to be switched off. Finally, in HVAC centralised systems, a dedicated panel is installed to interact with the HVAC system and enable the disconnection of devices. Actions performed in UPV buildings, and their relevance, are presented in Table 2.

Furthermore, lighting circuits are controlled. Two external luminosity sensors switch off areas with external lighting during daylight hours – as well as turning off external lights in public areas.

Table 2. HVAC centralised system actions.

Action	Description	Relevance
HVAC system consumption must avoid peak price hours	HVAC must be turned on in advance to produce the initial peak consumption in valley periods	High
Switch off the production of HVAC half an hour before closing the building	To take advantage of the inertia of the water in the pipe network, hot/cold production must be turned off half an hour before closing the building	High
Set temperature must be accurate	Laboratories, computer labs, conference rooms, etc. must have a proper set temperature when many people are expected	Medium
Frequency drives on the secondary cooling systems.	Energy consumption in the secondary piping circuit must be lowered by reducing the water flow to the building when thermal requirements decrease	Low
Force shutdown of chillers, heat pumps, and primary pumps when not needed	In seasons when thermal requirements are low, cold/hot production must be switched off (for parallel configuration)	High
Program the local PLCs to ensure that hot and cold valves are not open simultaneously	In fan coils and air handling units avoid simultaneous opening of hot and cold valves with a proper definition of the dead band	Low
All thermostats must enable users to switch off the fan and select fan speed	Users must be able to switch off fan when air-conditioning is not needed	High
Air handling units must have a correct schedule and enable users to switch off locally	Normally air handling units do not have a local control and are scheduled through the control system. Local control enables managers to disconnect locally when not necessary	Medium
The fan in fan coils must turn off when set temperature is reached	Programming of fan coil controllers must switch off the fan when temperature is under the limits	Medium
In moderate temperature seasons parts of the air-conditioning systems must be switched off	In seasons when there are no thermal requirements all unnecessary air-conditioning devices must be switched off	Medium
Adjust the switching of the production system in the first hour of the morning to the minimum necessary	Avoid connecting the system too early	High
Air-conditioning system switch-off during nights and holidays	Holidays and local holidays must be defined annually.	High
Location of chiller plants	Chiller plants must be located in shady areas to maintain the coefficient of performance as high as possible	Medium
Maintain remote control of devices	Pumps or chillers must be connected to manual mode when a problem occurs – and when the problem is solved technicians must remember to return to automatic mode	High

As mentioned, the use of a PLC to schedule and control lighting circuits, such as public lighting circuits, is more useful than employing timers.

The implemented controls switch off the lighting system. Users are responsible for switching on. The PLC only switches the circuits off when there is enough daylight, during holidays, etc. Connections performed are shown in Figure 3.

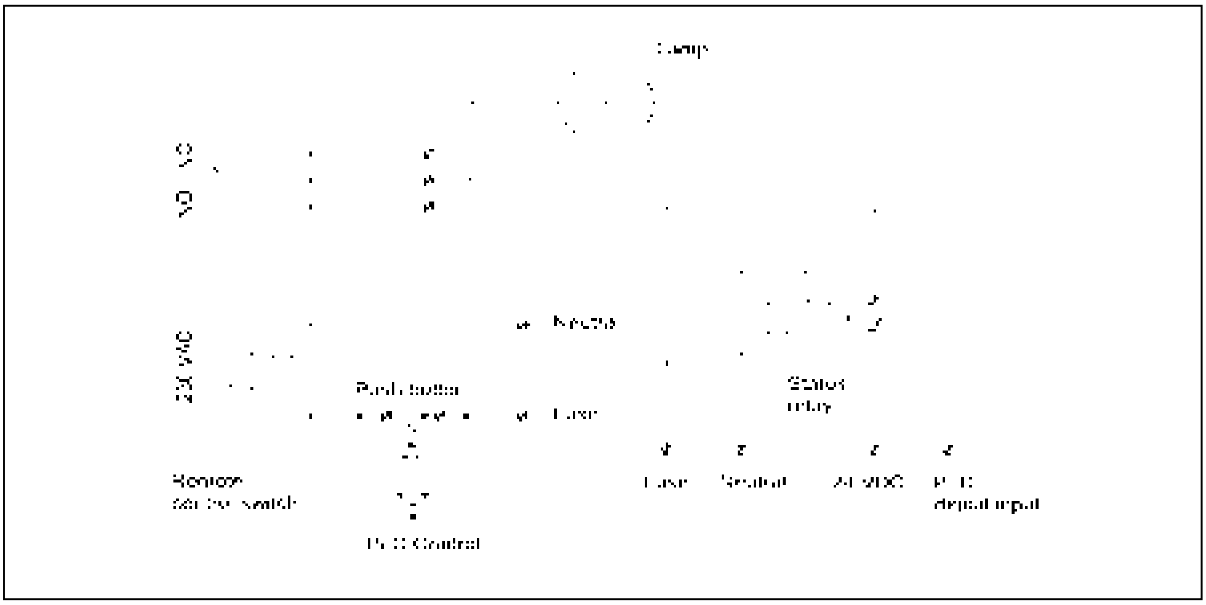


Figure 3. Remote control switch connection in UPV for lighting control.

Different areas have been adjusted in the UPV. Control has been gained of many lighting circuits in corridors and common areas in function of the external luminosity level. In this way, energy waste is automatically avoided by adjusting the internal lights.

4.5 Modify premises for easier management and lower consumption

In the use stage of a building, after the construction phase, it is important to analyse the real energy consumption of the building and identify malfunctions due to construction errors or changes in the uses of certain areas.

Malfunctions of some devices that persist from the construction phase should be solved to ensure a successful operation of the system.

The individual responsible for the consumption of a building must analyse problems in the premises and propose changes to ensure better use. In the following, the most common systems in the UPV, where actions have been implemented, are discussed.

Interior lighting system

Common actions include modifying lighting circuits to adjust to the real requirements. Some examples of the adjustments include:

- Changing the number of luminaries; installing switchers to connect only specific areas; divisions of an area into two circuits.

- Lighting circuits in waiting rooms have been divided into two circuits, so the users can leave one on and the other is controlled by a motion detector. Only one circuit is left on when nobody is in the room.

- Motion detectors have been installed to turn off the lights when nobody is in a storeroom.

- All of the toilets have been modified. Timer switchers have been installed in individual toilets and motion sensors have been installed at the entrance and cubicle areas of communal toilets.

Lighting in garages

Significant savings have been achieved by segmenting lighting circuits. Two lighting levels are defined in garages: security level and in-use level. Motion detectors are installed at the entrances of the garage and control the lighting of several circuits (two-thirds of the total lights). Another action has been to change the lighting in the access zone to be on continuously and some unnecessary circuits are switched off all day. Moreover, circuits in areas with sufficient external light are automatically switched off.

Lighting in service tunnels

Circuits are controlled by a PLC. One-third of the lights are on during the day, when people usually access the tunnels. When users require more light they can push buttons installed along the length of the tunnel and the PLC ensures that the lights are turned off 20 minutes later.

Public street lighting

Public lighting circuits are controlled by the level of daylight using a luminosity sensor. Additionally, flow reducers are connected at 10.00 pm to reduce consumption. Decorative light circuits have been made independent depending on the type of lamp and switch off at 23:30.

The use of individual lighting sensors in buildings is avoided. A single luminosity sensor is used and various circuits are activated depending on the level of daylight. In this way, manual operation is avoided.

4.6 Communication between managers and users

The Derd system has a web page, where managers and users can share information. This enables proper communication and therefore facilitates the adaptation of the use of the different facilities to the requirements of the users. This further enables historical data to be stored and managed to improve energy use [22].

4.7 Construction phase

As mentioned in the introduction, the construction phase plays a crucial role in determining the energy efficiency of buildings (e.g. through insulation). This however does not have to be limited to measures such as e.g. insulation or design of facilities. Proposals at the UPV for the construction of new buildings furthermore aim to facilitate an energy efficient property management on a different scale.

For the construction of new buildings in the UPV campus, architects have proposed to construct separate buildings based to their distinct end-uses. Thus, different building should be designated for different uses, i.e. classrooms, offices, administration, etc. This enables the establishment of more accurate schedules. For example, in August, buildings with only classrooms can be completely closed and the central air-conditioning system switched off.

The HVAC must be designed to take into account the end-use of each area. A proper design of the premises enables a better use.

Buildings for offices, classrooms, or administration, must be conditioned by individual systems (splits, VRV, etc.). These systems adapt better to the specific use of the building (users switch on the HVAC device when they are in the building). Centralised systems should only be used in unusual buildings, with large conditioned spaces, large and high halls, auditoriums, etc.

Motion detectors in toilets and automatic control of the lightning in common areas are proposed in new buildings. As nobody feels responsible for these areas, energy is sometimes wasted.

Appropriate facades, adequate fencing and insulation, and proper design of the HVAC systems are very important to obtain an adequate energetic behaviour during the use stage of the building.

5 Conclusion

In many situations, the actions of non-specialised technicians and end users determine the energy consumption of a building. This paper presents basic actions to improve energy efficiency in commercial buildings during the use stage.

These actions can be summarised into seven groups. The first is accurate measurement and storage of consumption data. Secondly, a proper schedule of expected room utilisation must be made. Thirdly, consumption must be automatically monitored and alerts sent to managers if consumption is excessive. Fourthly, an individual must be made responsible for consumption in each building. Fifthly, pro-active actions are necessary to ensure an adequate consumption (e.g. air-conditioning system switch-off during nights and holidays). Sixthly, facilities must be modified to enable easier management. And finally, communication should be established between users and the building manager.

These actions have been tested in several buildings at the Universitat Politècnica de València (UPV) and considerable financial savings are being made.

All these actions can be achieved using the existing building control system or using dedicated software. A new specialised program has been developed to improve the energy efficiency and management of the facilities at the UPV. This application gives the building manager tools to manage the premises more efficiently.

6 Acknowledgments

This research work has been possible with the support of the Universitat Politècnica de València through grant CE19990032.

7 References

[1] I. Zabalza Bribián, A. Aranda Usón, S. Scarpellini, Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification, Building and Environment (44) (2009) 2510-2520.

[2] Beatriz Rosselló -Batle, Andreu Moià, Antoni Cladera, Víctor Martínez. Energy use, CO2 emissions and waste throughout the life cycle of a sample of hotels in the Balearic Islands. Energy and Buildings (42) (2010), 547-558.

[3] X. García Casals, Analysis of building energy regulation and certification in Europe: Their role, limitations and differences, Energy and Buildings (38) (2006) 381-392.

[4] G. Escrivá-Escrivá, C. Álvarez-Bel, E. Peñalvo-López. New indices to assess building energy efficiency at the use stage. Energy and Buildings (43) (2011) 476-484.

[5] G. Escrivá-Escrivá, C. Álvarez-Bel, I. Valencia-Salazar. Method for modelling space conditioning aggregated daily load curves: Application to a university building. Energy and Buildings (42) (2010) 1275-1282.

[6] European Commission. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Official Journal of the European Communities. Available on: http://europa.eu/scadplus/leg/en/lvb/l27042.html, 2009.

[7] T. Ramesha, Ravi Prakasha, K.K. Shuklab. Life cycle energy analysis of buildings: An overview. Energy and Buildings (42) (2010), 1592-1600.

[8] C. Álvarez-Bel, M. Alcázar-Ortega, G. Escrivá-Escrivá, A. Gabaldón, Technical and economical tools to assess customer demand response in the commercial sector, Energy Conversion and Management (50) (2009), 2605-2612.

[9] M. Alcázar-Ortega, G. Escrivá-Escrivá, I. Segura-Heras. Methodology for validating technical tools to assess customer demand response. Application to a commercial customer. Energy Conversion and Management (52) (2011) 1507-1511.

[10] C. Álvarez-Bel, A. Gabaldón, I. Valencia-Salazar, M. Alcazar-Ortega, G. Escrivá-Escrivá. Market integration of responsive customers: Application to energy and balancing markets. International Journal of Power and Energy Systems, Vol. 29, No. 1, 2009.

[11] I. Valencia-Salazar, C. Álvarez-Bel, G. Escrivá-Escrivá, M. Alcázar-Ortega. Simulation of demand side participation in Spanish short term electricity markets. Energy Conversion and Management. DOI 10.1016/j.enconman.2011.02.005.

[12] I. Segura-Heras, G. Escrivá-Escrivá, M. Alcázar-Ortega. Wind farm electric power production model for load flow analysis. Renewable Energy (36) (2011) 1008-1013.

[13] Eric Martinot, Nils Borg. Energy-efficient lighting programs. Experience and lessons from eight countries. Energy Policy. Vol. 26, No. 14, pp. 1071-1081, 1998.

[14] Brenda Boardman. Achieving energy efficiency through product policy: the UK experience. Environmental Science & Policy (7) (2004) 165-176.

[15] Oyeshola F. Kofoworola, Shabbir H. Gheewala. Life cycle energy assessment of a typical office building in Thailand. Energy and Buildings (41) (2009), 1076-1083.

[16] G. Escrivá-Escrivá, M. Alcázar-Ortega, C. Álvarez-Bel. “Integral Management System for the energy efficiency improvement in commercial facilities: Application to the Polytechnic University of Valencia”, Proc. International Conference on Renewable Energies and Power Quality, April 2009.

[17] G. Escrivá-Escrivá, I. Segura-Heras, M. Alcázar-Ortega. Application of an energy management and control system to assess the potential of different control strategies in HVAC systems, Energy and Buildings (42) (2010) 2258-2267.

[18] W. Kastner, G. Neugschwandtner, S. Soucek, H. M. Newman. Communication systems for building automation and control. Proceedings of the IEEE, No. 6, Vol. 93, June 2005.

[19] Maintenance service, Universitat Politècnica de València. Inventario de equipos e instalaciones, 2009.

[20] Weather data per quarter of an hour, available on: http://www.wunderground.com/, January 2009.

[21] M.W. Ellis, E. H. Mathews. Needs and trends in building and HVAC system design tools. Building and Environment (37), pp. 461-470, 2002.

[22] G. Escrivá-Escrivá, C. Álvarez-Bel, J. Rodriguez-Garcia, F. Mugarra-Llopis. Distributed energy resources and demand management system. Available on www.derd.upv.es, March 2011.

A Method for Determining the Relationship between Energy Performance Certification and Workplace Satisfaction

Parkinson A.T.[1], De Jong R.[2], Cooke A.J.[1]

[1]Centre for Sustainable Development, Cambridge University Engineering Department

[2]LessEn, Urban Land Institute

Abstract

Energy efficiency in the workplace is characterised by high transaction costs, and therefore many governments have introduced energy performance labelling and certification to property. There is existing statistical evidence of transaction and rental premia associated with such schemes, predominantly supported by the CoStar© dataset of the US market. It is understood that occupants are the true end-users of workplaces, and subsequently should be treated as customers by those that provide the facilities they occupy. Therefore, this study explores the relationship between workplace satisfaction and Energy Performance Certificates (EPC). Two social constructs were developed, measuring occupant satisfaction and importance with different aspects of their workplace, following theory of performance measures of service quality (SERVPERF). These were included in a survey that resulted in 96 responses. The constructs of satisfaction and importance exhibited Cronbach's Alpha coefficients of 0.93 and 0.59 respectively. Significant correlations were found between a small sample of EPC Asset Ratings and all the items of the satisfaction construct except workplace location. This preliminary evidence provides some confirmation of SERVPERF measures of service quality. It also supports the view that EPC's are useful performance measures of the overall quality of a workplace irrespective of location, and that the contribution of energy performance to workplace satisfaction cannot be determined discretely by attempting to measure the statistical effects of certificates or labels. This would imply that prospective tenants and owners who pay high regard to EPC's could be provided with valuable insights into the expected satisfaction on occupation of a workplace.

Energy Performance Labelling and Certification

Energy Efficiency has been defined as actions that have the consequence of both decreasing energy intensity and increasing economic efficiency [1]. More efficient energy consumption can lead to improved energy security, increased economic development and competitiveness, improved public health, and climate change mitigation [2]. Many government organisations have identified these benefits and subsequently energy efficiency has become of increasing priority, for example with members of the OECD.

The Scale of Opportunity

The IEA has published annual statistics on energy use across the world. They assert that global energy consumption has almost doubled since 1971 from approximately 4500 Mtoe to 8500 Mtoe and is maintaining this trend [3]. Cullen and Allwood mapped global energy flows in order to assess where to best focus efforts for mitigating climate change impacts. The results show that 11353Mtoe (475EJ) of energy is consumed by end users globally. Of this total it shows that buildings are responsible for 5139Mtoe (215EJ, 45%) of energy consumption. 2151Mtoe (90EJ, 19%) is consumed to provide thermal comfort, making this the most significant single end use of energy throughout all sectors. Cullen and Allwood admit that this analysis is at best a good estimate and does not complement the findings of the International Energy Agency [4]. One third of the world's primary energy consumption is converted into useful energy [5]. Therefore, the built environment represents a highly significant prospect for the conservation of energy, where improvements may have a substantial overall impact on the requirements for energy infrastructure.

Addressing Barriers to Energy Efficiency in the Built Environment

The energy efficiency gap refers to the disparity between apparent cost-optimal levels of investment based on the analysis of engineers, and lower levels actually occurring in society. There is consistent historical evidence of investments in energy efficiency providing very high rates of return compared with the economy wide average cost of capital [6][7][8].

Blumstein et al. compiled one of the earliest systematic taxonomies of barriers to energy efficiency. Through a process of interviews, he found numerous barriers that he felt warranted political intervention and further research [9]. A number of further qualitative studies also identified barriers and recommended political action to address barriers to energy efficiency [10][11][12][13].

The initial claims of barriers to energy efficiency have been criticised as lacking economic rigour. This criticism takes a neo-classical economists view that the barriers identified are not ‘market failures’, and therefore do not constitute a political response. Many have suggested that the slow diffusion of new energy technologies may not be the result of consumer ignorance. Instead, they assert observed behaviour is consistent with the results of rational cost minimizing behaviour [14] [15] [16] [17]. This implies that government and regulatory policies attempting to promote energy conservation cannot be based on the failure of private markets to make efficient decisions [17].

The underlying assumption of the neo-classical economic perspective is that all actors operate rationally (normally), even if unintentionally so [18]. This assumption has been highly contested, notably by Sanstad & Howarth, who assert that the existence of such barriers can be rooted in consumers ‘bounded rationality’ and ‘imperfect information’, which may lead to real world outcomes that deviate from the dictates of efficient resource allocation [19]. These concepts are underpinned by the work of Coase who demonstrated that market failures disappear if decisions are taken with an understanding that transactions were costless [20]. This leaves open the potential for political intervention to mitigate barriers to energy efficiency when the cost of administration and enforcement are less than the associated benefits. In his Nobel Prize Lecture Coase states “*The process of contracting needs to be studied in a real world setting. We would then learn of the problems that are encountered and of how they are overcome...*” [21].

Sorrel et al developed a multidisciplinary taxonomy of barriers to energy efficiency that explained alternative economic, behavioural, and organisational perspectives [22]. All three perspectives recognise barriers involving information dissemination. Golove and Eto describe an economist’s perspective of how imperfect information can affect decision making: consumers may lack information on the energy performance of technologies; costs are associated with searching and acquiring information on energy performance; and accurate, unbiased information may be difficult to obtain [1]. Stern takes a behavioural perspective to describe how the form of information can be a barrier to energy efficiency: the cost of searching does not seem to be the main reason for a lack of understanding; the effectiveness of information depends on its availability and content [23]. Lutzenhiser takes an organisational perspective in emphasising the crucial role played by figures of influence in shaping the values that guide an organisation [24]. A measure that many governments have taken to address these specific barriers to efficient energy consumption in buildings is to introduce energy performance labelling and certification. In theory, such schemes should address barriers to energy efficiency in the following ways:

- Imperfect information (economic perspective) – EPC’s provide information that enables consumers to determine quality when making decisions to purchase items bought infrequently, involving complex technologies.
- Form of information (behavioural perspective) – EPC’s provide specific, vivid, and simple information close to the time of decision making.
- Culture (organisational perspective) – EPC’s enhance the status of energy management and encourages a culture of energy efficiency.

The Political Landscape

Energy Performance Certificates In the UK

On the 16th December 2002 the European Parliament and Council passed Directive 2002/91/EC on the energy performance of buildings (EPBD). The objective of this Directive was to promote improved energy performance throughout the European Community (EU). The motivation for this legislation was partly as a response to the obligations placed on the EU to as signatories to the Kyoto Protocol[1]. EPBD stipulated a general framework for a methodology for calculating the energy performance of buildings. Member States were required to produce their own national calculation method, but a minimum specification for this was imposed by the Directive. Under the EPBD all Member States were required to ensure that every building sold constructed or rented out was provided with an energy performance certificate (EPC), displaying a comparative asset rating [26]. In 2010 the Directive was recast in response to the European Council of March 2007 which emphasised the need for energy efficiency in order to move towards its goal of reducing the European Union's energy consumption by 20% by 2020 [27].

On the 29th March 2007 the Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations 2007 was given royal assent. The UK government sought to encourage owners and tenants to choose energy efficient buildings when seeking accommodation and improve the performance of buildings they occupy [28]. A Departmental Notice stipulated that an EPC Asset Rating of a non-domestic dwelling in the UK is an indicator of the calculated annual CO2 emissions associated with space heating, water heating, ventilation, air-conditioning and lighting in average circumstances. The Asset Rating should be displayed on energy performance certificates as a graphic banding system ranging from A+ to G [29].

Energy Star Labelling In the USA

The US Environmental Protection Agency introduced the Energy Star program in 1992 as a voluntary labelling program designed to identify and promote energy efficient products. Initially these labels were applied to computers and monitors. Since 1995 Energy Star labelling has expanded to label major appliances, office equipment, lighting, home electronics, new homes, and commercial and industrial buildings [30]. The label provides a benchmark that indicates when a buildings energy performance is equivalent to the top 25% of comparable buildings [31].

Quantitative Measures of Purchase Intentions

Statistical Evidence of Labelling and Certification Impacting Financial Performance

The existing statistical evidence for transaction and rental premia derived from the energy performance labelling and certification of offices is reviewed by Parkinson and Cooke, in an investigation into an emerging consensus in price comparison studies. The findings of a number of publications using hedonic regression to associate office attributes with proportions of asking rents, transaction prices, and occupancy rates were reviewed and are summarised in Table 1.

Measuring Expressions of Satisfaction

An influential conceptual model of service quality has been developed by Parasuraman et al. through an exploratory study involving in-depth interviews and a set of consumer focus groups. The conceptual model developed a theory that perceived service quality can be determined through a function of two measures: customer expectations of a service; and customer perceived service performance [40]. This research formed the basis of the SERVQUAL item scale, introduced by

[1] (United Nations, 1998) [25]

Parasuraman et al. to measure service quality, for which 200 responses were gathered. The internal consistency of the scale was measured using Cronbach's Alpha and ranged from 072-0.87 across 5 dimensions, with an overall reliability of 0.87-0.9. Cronbach's alpha coefficients have a scale between 0 and 1, higher scores indicating greater reliability. Each dimension had low inter-correlations [41].

A study by Pinder took a SERVQUAL approach, measuring service quality in the workplace by weighting a social construct measuring occupant perceptions of performance against a construct measuring occupant expectations. The item scale considered the effects of the indoor environment, functionality, aesthetic appearance, and configuration on workplace satisfaction. The resulting framework was demonstrated to be a highly reliable measure, with a Cronbach's Alpha of 0.93, achieved through replacing missing data with the calculated mean of the corresponding items [42].

Cronin & Taylor disputed SERVQUAL measures as lacking theoretical and empirical support. Research was conducted into whether SERVQUAL was a more valid measure of service quality than simple performance measures (SERVPERF). The study gathered 660 complete questionnaires from a random sample of residents on the service quality provided by four industries: banking; pest control; dry cleaning; and fast food. The study findings suggest that service quality should be conceptualised and measured as an attitude, and that a performance only (SERVPERF) measures describe variations in service quality better than SERVQUAL approaches. The study asserts that SERVQUAL measures are flawed as: they are based upon a satisfaction paradigm rather than an attitudinal model; SERVQUAL models are not shown to be empirically valid in all industries. The study provides empirical support to suggest that perceived service quality leads to satisfaction, and that satisfaction has a more strongly significant effect than service quality on purchase intentions. Thus, an emphasis on total customer satisfaction exerts stronger influence on purchases than service quality [43].

Lee took a SERVQUAL approach to intensively measure workplace satisfaction in four office buildings occupied by three different organisations. The survey yielded 409 responses, of which 384 were analysed. The study principally attempted to affirm the following hypotheses: SERVQUAL measures were stronger predictors of workplace satisfaction than SERVPERF measures - not confirmed by the study; occupant satisfaction with the physical workplace environment is positively associated with job satisfaction - confirmed by the study [44].

Table 1: A review of evidence of multiple premia for offices endorsed by the Energy Star label.

Study	Attribute Data	Premium / % (No. of offices in sample)	
		Transaction	Asking Rent
Wiley et al., 2008[2] [32]	CoStar©		7-9 (?)
Miller et al., 2008[3] [33]	CoStar©	6-11 (7 308)	
Fuerst & McAllister, 2009 [34]	CoStar©	31 (662)	5 (800)
Fuerst et al., 2010 (trimming)[4] [35]	CoStar©	15 (2397)	5 (2397)
Fuerst et al. 2010 (without trimming) [35]	CoStar©	30 (2397)	5 (2397)
Eichholtz et al., 2010 [36]	CoStar©	15.8-16.8 (1074)	3.3 (1074)
Eichholtz et al., 2010 [37]	CoStar©	15.8-16.8 (?)	3.3 (?)
Pivo & Fisher, 2010 [38]	National Council of Real Estate Investment Fiduciaries	8.5 (1 199)	2.7 (1 199)

Parkinson & Cooke, 2011 [39]

[2] Did not take into account a trend for certified buildings to be located in better quality locations within a metropolitan area or dual certification [35].

[3] Refer to footnote 1.

[4] 'Trimming' refers to corrections made to outliers in the data caused by error. In the robust model outliers are identified by their Cooks distance, distances larger than 1 were automatically given a zero weight in the estimation. Cook's distance measures the effect of deleting a given observation based on its residual in the regression and leverage in the estimation process [36].

Methodology

The evidence provided by the price comparison studies discussed are predominantly supported by datasets of US offices made available by CoStar© and US Department of Energy. An alternative perspective is needed to this analysis, investigating the effect of these programmes on other regions of the world, such as EPC's in the UK. There is also a developing understanding that occupants are the true end-users of buildings, and therefore should be treated as customers by those that provide the facilities they occupy [45]. Therefore, it could be useful to study occupant attitudes towards their workplace with relation to an objective measure of service performance, such as EPC asset ratings. This would provide policy makers with a further understanding of the significance EPC's in UK real estate markets when evaluating policy success.

It was determined that a means of fulfilling the research objective would be to conduct an extensive attitudinal survey. The domain of construct should be occupant satisfaction with their workplaces. A theoretical framework consisting of 11 workplaces attributes as items was selected through a literature review. Table 2 describes the item scale, along with details of the principal sources that supported item selection. This item scale considers a broader selection of workplace attributes than reviewed studies. The items were qualified both in terms of occupant satisfaction (Construct A) and perceived importance (Construct B) by occupants on 7 point Likert scales[5], in accordance with SERVPERF methods. This theory was supported by Cronin and Taylor, who explored the possibility that the customer satisfaction of a service could be determined either through the product of the perceived importance and performance of a service, or simply its performance only [43]. Therefore, the question wording for Construct A was "*How satisfied are you with the following attributes of your current workplace?*", and Construct B "*How important are the following attributes of a workplace to you?*". These constructs could then be checked for internal consistency and compared with objective measures of workplace performance, such as EPC asset ratings. A number of other moderating variables were introduced as separate questions to the survey, to further qualify responses. The survey included very few compulsory questions which were required only for the survey logic to be carried out appropriately online. The resulting survey was pilot tested through 10 interviews of workplace occupants.

Table 2: The 11 item scale of workplace attributes used for Constructs A & B.

Principle Supporting Literature	Item (Workplace Attribute)	Item Code
Parkinson & Cooke, 2011 [39]	Energy performance, as defined by label or certificate	1
Parkinson & Cooke, 2011 [39]	Property environmental performance, as defined by label or certificate (e.g. BREEAM, LEED)	2
DECC, 2010 [46]	Operational environmental impact	3
DiPasquale & Wheaton, 1996 [47]	Running costs (including rent, service charge, and energy costs)	4
Pinder J., 2003 [42]	Configuration (including space requirements and adaptability)	5
Pinder J., 2003 [42]	Indoor environment (including comfort, acoustics, air & lighting quality and control)	6
Pinder J., 2003 [42]	Aesthetic appearance (including cultural significance)	7
Bordass B. et al 2001 [48]	Occupant understanding of how the building operates	8
Bordass B. et al 2001 [48]	Property managers understand workplace sustainability needs	9
Pinder J., 2003 [42]	Functionality (including level of distraction, privacy, storage space, security and IT provision)	10
DiPasquale & Wheaton, 1996 [47]	Location (including proximity to public transport, accessibility, retail, other businesses, and outdoor space)	11

[5] A one-dimensional scaling method for quantifying question responses.

The survey is currently being hosted by SurveyMonkey®[6] and web links have been posted on the LessEn blog[7] since the 21st November 2011. Promotion of the survey has been conducted principally through social media. Respondents are encouraged to leave their answers to responses blank if they do not know how to answer a question. The survey is being actively promoted by the authors in order to attract as many responses as possible. This paper draws upon raw data downloaded on the 17th January 2012 for preliminary analysis. In total the survey attracted 96 responses to this date.

Results and Analysis

It is important to note that the sample of responses to the survey cannot be considered random, as the survey has been predominantly marketed through the authors affiliated networks, which have been acknowledged at the end of this paper. Therefore, the analysis should be considered in terms of the mediating questions included in the survey. The vast majority of responses to the survey were private sector employees, as shown in Figure 1. Figure 2 shows that most responses came from workplace occupants situated in London. Table 3 shows the size of organisations that respondents worked for, showing that the majority were part of large organisations of 500+ employees, although more than half of the respondents worked in offices accommodating less than 50 people. 40% of respondents were unable to state the EPC Asset Rating of their workplace, and 39% of workplaces were found to have never had energy performance certified in this way.

The internal consistency of the two proposed social constructs was determined by calculating Cronbach's alpha coefficients from the survey results using R code[8]. As alpha coefficients are not robust when used to assess incomplete data, all incomplete records were omitted from the test sample, resulting in 31 records being tested. The tests found alpha coefficients of 0.93 for Construct A, and 0.59 for Construct B. Each item of Construct A returned a Cronbach's Alpha above 0.92, which indicates that factor analysis was unlikely to improve reliability. The results of Construct B are evidently questionable [51]. This indicates that proposed Construct A has excellent reliability and contends with the framework developed by Pinder, also with an Alpha coefficient of 0.93 [41].

Analysis to determine Pearson (r) and Spearman (ρ) correlation coefficients describing the strength of associations between Construct A items and EPC Asset Rating were made using R code[9][10]. This was carried out using datasets that excluded responses of 'no certificate', or where the EPC Asset Rating was not specified. From this analysis, all items other than workplace location were found to have less than a 0.05 two-tailed probability of no association using both methods. Descriptive statistics of the correlations can be found in Table 4.

---

[6] SurveyMonkey, 2012 [49]

[7] LessEn, 2012 [50]

[8] Wessa P., 2010 [53]

[9] Wessa, 2008 [53]

[10] Wessa P., (2009 [54]

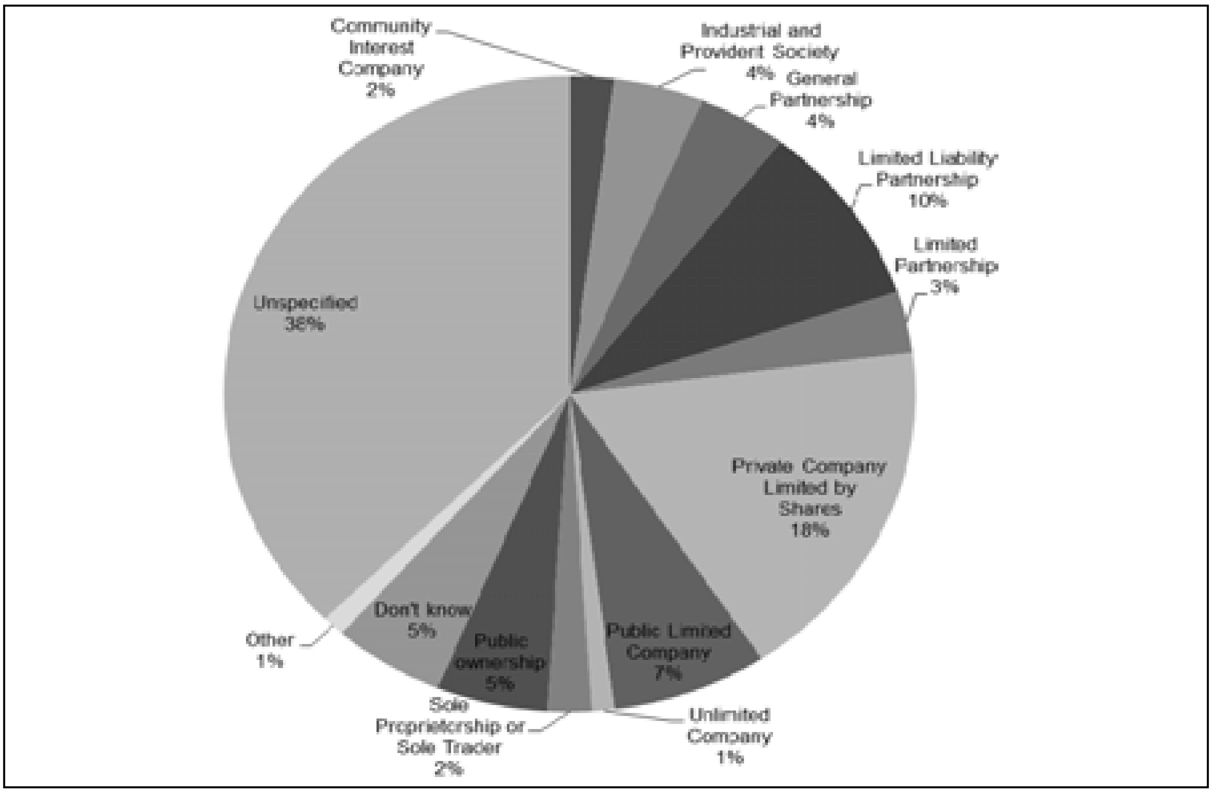


Figure 1: Types of Organisations Which Respondents Work for

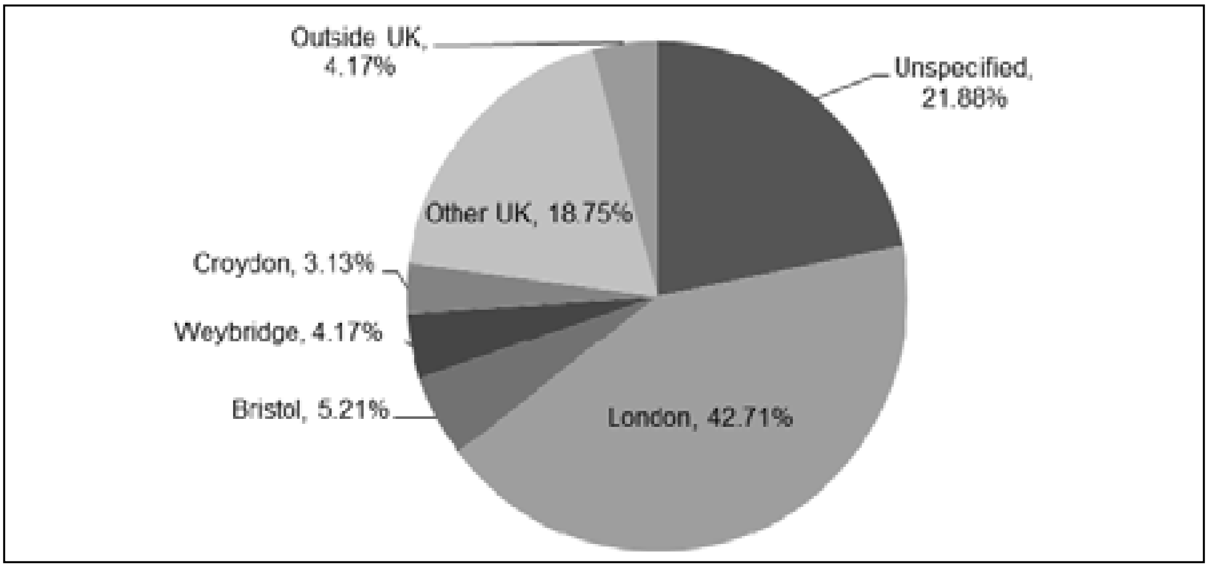


Figure 2: Location of Respondents Workplace

Table 3: Sizes of Respondents Organisations and Workplaces

Quantity	0-9	10-49	50-249	250-499	500+	Unspecified
Employees in entire organisation / %	6	6	10	4	28	46
Occupants in respondent workplace / %	7	18	10	5	8	52

Conclusions and Recommendations

This paper has identified evidence of a distinct energy efficiency gap that is best explained by the existence of market failures, resulting in high transaction costs for improvement. Many governments around the world have introduced energy performance labelling and certification to commercial property to address this. Two of the most widely adopted schemes are the Energy Star label (USA), and EPC's (EU). Statistical studies of US office markets show consensus surrounding the existence of asking rent and transaction premiums for Energy Star labelled offices, largely dependent on data provided by CoStar© and the US Department of Energy.

This research seeks to take an alternative perspective to previous studies by measuring UK occupant attitudes towards their workplace in relation to EPC's. Two social constructs were developed, measuring occupant satisfaction and importance with different aspects of their workplace, following theory of performance measures of service quality (SERVPERF). These were included in a survey that resulted in 96 responses. The responses were gained almost entirely from private sector employees, many of which were situated in London. More responses were received from larger organisations than others. Only a small proportion of respondents were able to state an EPC Asset Rating for their workplace.

The constructs of satisfaction and importance exhibited Cronbach's Alpha coefficients of 0.93 and 0.59 respectively from a sample of 31 complete records. This indicates that the construct measuring occupant satisfaction has excellent reliability and contends with the framework developed by Pinder, also with an Alpha coefficient of 0.93

Significant associations, using both Pearson and Spearmen methods, were found between known EPC Asset Ratings and all aspects of workplace satisfaction except location. However, it must be noted that the sample of consistent data available for analysis in this survey is small and much caution should be taken in its interpretation.

Table 4: Correlations between Social Construct A and EPC Asset Rating[11]

Item Code	N	R	r^2	2-p(r)	ρ	2-p(ρ)
1	14	-0.74	0.55	<0.01	-0.79	<0.01
2	11	-0.77	0.59	<0.01	-0.78	<0.01
3	14	-0.64	0.41	0.01	-0.83	<0.01
4	14	-0.76	0.57	<0.01	-0.76	<0.01
5	14	-0.68	0.47	0.01	-0.79	<0.01
6	14	-0.77	0.60	<0.01	-0.90	<0.01
7	13	-0.72	0.52	0.01	-0.82	<0.01
8	12	-0.68	0.46	0.01	-0.80	<0.01
9	13	-0.46	0.21	0.11	-0.65	0.02
10	13	-0.60	0.36	0.03	-0.77	<0.01
11	13	-0.15	0.02	0.63	-0.09	0.77

[11] n = number of observations; r = Pearson correlation coefficient; r2 = coefficient of determination; ρ = Spearman correlation coefficient; 2-p() = two-tailed probability of null hypothesis that there is no association.

Plausible explanations that could explain such associations are that: significant improvement of one attribute of a workplace requires consequential improvements to others; occupants do not perceive the correlated workplace attributes as being independent from each other when responding to the survey; property managers who succeed in addressing energy performance are also adept at providing facilities with other attributes of similar quality; the ability of design teams to address energy performance is indicative of how well they can address other attributes in developing workplaces; organisations, with whom job satisfaction is high, occupy workplaces with high energy performance.

This tentative analysis provides some confirmation of SERVPERF methods. EPC Asset Ratings have been found to not only be associated with reduced costs and environmental impact, but also to have broader associations with overall employee satisfaction. Such associations could confound assertions that the price comparison studies described in Table 1 support the view that a change in occupant preferences is being observed with respect to environmental issues. These findings would indicate that the contribution of energy performance to workplace satisfaction could not be determined discretely by attempting to drawing associations between energy performance certificates or labels and purchase intentions.

These preliminary findings would indicate that EPC's could be useful measures of overall workplace quality irrespective of location. This would imply that prospective tenants and owners who pay high regard to EPC's could be provided with valuable insights into the expected satisfaction on occupation of a workplace.

Further Work

A larger sample of respondents is required to further study the preliminary correlations. Comparisons should be made between occupant satisfaction and EPC Asset Ratings due to be made available by the UK Government, under the provisions of the Energy Act 2011 [55], to understand whether observed associations between EPC Asset Ratings and the reliable construct remain when occupants are not aware of the rating. Comparisons with rents could also further validate the construct of occupant satisfaction. Further analysis should more carefully consider that the sample is not random.

Acknowledgements

The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC), Modern Built Environment Knowledge Transfer Network (MBEKTN), Grosvenor, the Urban land Institute, the LessEn Initiative, and Stanhope for funding this research. The UK Green Building Council, Low Carbon Workplace Ltd., Better Buildings Partnership, 2 Degrees Network, and Planet Positive have also supported this study.

References

[1] W H Golove and J H Eto, "Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency," University of California, Berkeley, 1996.

[2] International Energy Agency, "Energy Efficiency Governance," OECD, Paris, 2010.

[3] International Energy Agency, "Key World Energy Statistics," OECD, Paris, 2010.

[4] J M Cullen and J M Allwood, "The Efficient Use of Energy: Tracing the Global Flow of Energy from Fuel to Service," *Energy Policy*, vol. 38, no. 1, pp. 75-81, 2010.

[5] D R Limaye, G C Heffner, and G C Sarker, "An Analytical Compendium of Institutional Frameworks for Energy Efficiency Implementation," The World bank Group, Washington, 2008.

[6] R S Hartman and M J Doane, "Household Discount Rates Revisited," *The Energy Journal*, vol. 7, no. 1, pp. 139-148, 1986.

[7] J A Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," *The Bell Journal of Economics*, vol. 10, no. 1, pp. 33-54, 1979.

[8] F P Sioshansi, "The Myths and Facts of Energy Efficiency," *Energy Policy*, vol. 19, no. 3, pp. 231-243, 1991.

[9] C Blumstein, B Kreig, L Schipper, and C York, "Overcoming Social and Institutional Barriers to Energy Conservation," *Energy*, vol. 5, pp. 355-371, 1980.

[10] S Craig and J M McCann, "Assessing Communication Effects on Energy Conservation," *Journal of Consumer Research*, vol. 5, no. 2, pp. 82-88, 1978.

[11] E Hirst and M Brown, "Closing the Efficiency Gap: Barriers to the Efficient Use of Energy," *Resources, Conservation and Recycling*, vol. 3, no. 4, pp. 267-281, 1990.

[12] E Gruber and M Brand, "Promoting Energy Conservation in Small and Medium-Sized Companies," *Energy Policy*, vol. 19, no. 3, pp. 279-287, 1991.

[13] P C Stern, "What Psychology Knows About Energy Conservation," *American Psychologist*, vol. 47, no. 10, pp. 1224-1232, 1992.

[14] K A Hassett and G E Metcalf, "Energy Conservation Investment, Do Consumers Discount the Future Correctly?," *Energy Policy*, pp. 710-716, 1993.

[15] G E Metcalf, "Economics and Rational Conservation Policy," *Energy Policy*, vol. 22, no. 10, pp. 819-825, 1994.

[16] A B Jaffe and R N Stavins, "The Energy-Efficiency Gap, What does it Mean?," *Energy Policy*, vol. 22, no. 10, pp. 804-810, 1994.

[17] R J Sutherland, "The Economics of Energy Conservation Policy," *Energy Policy*, vol. 24, no. 4, pp. 361-370, 1996.

[18] M Friedman, "The Methodology of Positive Economics," in *Essays in Positive Economics*. Chicago, USA: University of Chicago Press, 1953, ch. 1, pp. 3-43.

[19] A H Stanstad and R B Howarth, "'Normal' Markets, Market Imperfections and Energy Efficiency," *Energy Policy*, vol. 22, no. 10, pp. 811-818, 1994.

[20] R Coase, "The problem of social cost," *Journal of Law & Economics*, vol. 3, no. 1, pp. 1-44, 1960.

[21] R H Coase, “Prize Lecture,” 1991. [Online]. Available: http://www.nobelprize.org/nobel_prizes/economics/laureates/1991/coase-lecture.html. [Accessed 21 01 12].

[22] Sorrell S, Schleich J, Scott S, E O’Malley, F Trace, U Boede, K Ostertag, P Radgen, “Reducing Barriers to Energy Efficiency in Public and Private Organisations,” University of Sussex, Brighton, 2000.

[23] P C Stern, “What Psychology Knows About Energy Conversation” *American Psychologist*, vol. 47, no. 10, pp.1224-1232, 1992.

[24] L Lutzenhiser, “A Cultural Model of Household Energy Consumption” *Energy*, vol. 17, no. 1, pp.47-60, 1992.

[25] United Nations Framework Convention on Climate Change. (2011) UNFCCC. [Online]. HYPERLINK "http://unfccc.int/2860.php" http://unfccc.int/2860.php

[26] The European Parliament and the Council of the European Union, "Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings," *Official Journal of the European Communities*, vol. 2003, pp. 65-71, January 2003.

[27] The European Parliament and the Council of the European Union, "Directive 2010/31/EU of the European Parliament and of the Council of the 19th May 2010 on the energy performance of buildings (recast)," *Official Journal of the European Union*, pp. 13-35, June 2010.

[28] C Sweetenham, The Energy Performance of Buildings (Certifications and Inspections) (England and Wales) 2007, 2007.

[29] Department for Communities and Local Government, Notice of Approval of the Methodology of Calculation of the Energy Performance of Buildings in England and Wales, 2008.

[30] US Environmental Protection Agency, US Department of Energy. (2011) ENERGY STAR. [Online]. HYPERLINK "http://www.energystar.gov/index.cfm?c=about.ab_history" http://www.energystar.gov/index.cfm?c=about.ab_history

[31] P Eichholtz, N Kok, and J M Quigley, "Doing Well by Doing Good? Green Office Buildings," Maastricht University/University of California, Maasticht/Berkeley, 2009.

[32] A J Wiley, J D Benefield, and K H Johnson, "Green Design and the Market for Commercial Office Space," *Journal of Real Estate Finance and Economics*, vol. 41, no. 2, pp. 228-243., 2008.

[33] N Miller, J Spivey, and A Florance, "Does Green Pay Off?," *Journal of Real Estate Portfolio Management*, vol. 14, no. 4, pp. 385-399, 2008.

[34] F Fuerst and P McAllister , "Green Noise or Green Value? Measuring the Price Effects of Environmental Certification in Commercial Buildings.," University of Reading, Reading, 2009.

[35] F Fuerst, P McAllister, and K Smith, "Eco-Labeling, Rents, Sale Prices and Occupancy Rates: Do LEED and Energy Star Labeled Offices Obtain Multiple Premiums?," University of Reading, Reading, 2010.

[36] P Eichholtz, N Kok, and J M Quigley, "Doing Well by Doing Good? Green Office Buildings.," *American Economic Review*, vol. 100, no. 5, pp. 2492-2509, 2010.

[37] P Eichholtz, N Kok, and J M Quigley, "The Economics of Green Buildings," Maastricht University/University of California, Maasticht/Berkeley, 2010.

[38] G Pivo and J D Fisher, "Income, Value and Returns on Socially Responsible Office Properties," *Journal of Real Estate Research*, vol. 32, no. 3, pp. 385-399., 2010.

[39] A T Parkinson and A J Cooke, "Market Responses to the Sustainability and Energy Performance of Commercial Property," in *Proceedings of the Third International Conference on Sustainability in Energy and Buildings*, Marseille, 2011, pp. 85-97.

[40] A Parasuraman, V A Zeithaml, L. L. Berry, “A Conceptual Model of Service Quality and Its Implications for Future Research” *Journal of Marketing*, vol. 49, no. 4, pp. 41-50, 1985.

[41] A Parasuraman, V A Zeithaml, L. L. Berry, “SERVQUAL: A Multiple-Item Scale for Measuring Consumer Perceptions of Service Quality” *Journal of Retailing*, vol. 46, no. 1, pp. 12-40.

[42] J Pinder, I F Price, S J Wilkinson, and S Demack, "A Method for Evaluating Workplace Utility," *Property Management*, vol. 21, no. 4, pp. 218-229, 2003.

[43] J J Cronin Jr, and S A Taylor. “Measuring Service Quality: A Reexamination and Extension” *The Journal of Marketing*, vol. 56, no. 3, pp. 56-68, 1992

[44] S Y Lee, “Expectations of employees toward the workplace and environmental satisfaction” *Facilities*, vol. 24, no. 9&10, pp. 343-353, 2006.

[45] F Szigeti, G Davis, A Atherton, and D A Henning, "Changes in the Relationships Between Customers and Providers of Facilities," in *Proceedings of the CIB W92 Symposium*, Montreal, 1997.

[46] Department of Energy and Climate Change, "Final Impact Assessment on the Order to Implement the CRC Energy Efficiency Scheme," Department of Energy and Climate Change, London, Impact Assessment 2010.

[47] D DiPascquale and W C Wheaton, "Non-Residential Property Markets," in *Urban Economics and Real Estate Markets*. Englewood Cliffs, USA: Prentice-Hall, 1996, ch. 5, pp. 91-123.

[48] B Bordass, A Leaman, and P Ruyssevelt, "Assessing Building Performance in Use 5: Conclusions and Implications," *Building Research and Information*, vol. 29, no. 2, pp. 144-157, 2001.

[49] SurveyMonkey. (2012) SurveyMonkey. [Online]. HYPERLINK "http://www.surveymonkey.com/" http://www.surveymonkey.com/

[50] LessEn. (2011, Nov.) www.less-en.org. [Online]. HYPERLINK "http://www.less-en.org/?page=blog&article=214&how-does-your-workplace-work-for-you" http://www.less-en.org/?page=blog&article=214&how-does-your-workplace-work-for-you

[51] J A Gliem., R R Gliem. (2003) “Calculating, Interpreting, and Reporting Cronbach’s Alpha Reliability Coefficient for Likert-Type Scales” in Proceedings of the Midwest Research to Practice Conference in Adult, Continuing, and Community Education, Columbus OH, 2003.

[52] P Wessa. (2010) Cronbach alpha (v1.0.1) in Free Statistics Software (v1.1.23-r7). Software. [Online]. HYPERLINK "http://www.wessa.net/rwasp_cronbach.wasp/" http://www.wessa.net/rwasp_cronbach.wasp/

[53] P Wessa. (2008) Pearson Correlation (v1.0.3) in Free Statistics Software (v1.1.23-r7). Software. [Online]. HYPERLINK "http://www.wessa.net/rwasp_correlation.wasp/" http://www.wessa.net/rwasp_correlation.wasp/

[54] P Wessa. (2009) Spearman Rank Correlation (v1.0.0) in Free Statistics Software (v1.1.23-r7). Software. [Online]. HYPERLINK "http://www.wessa.net/rwasp_spearman.wasp/" http://www.wessa.net/rwasp_spearman.wasp/

[55] UK Parliament, *Energy Act,* London: Her Majesty's Stationary Office, 2011.

Improving the Quality of Energy Retrofits Investment Decisions by Including Uncertainty in Energy Modeling Process – A Case Study

Alireza Bozorgi, PhD, MBA Candidate

School of Architecture + Design & Pamplin College of Business, Virginia Tech

James R. Jones, PhD

Professor of Architecture, School of Architecture + Design, Virginia Tech

Abstract

Currently, many investment decisions concerning energy retrofits are made directly based on the outcomes of energy simulations. However, there are various uncertainties inherent in the energy retrofit assessment process, both at the energy simulation and life cycle cost analysis (LCCA) levels, which can result in inaccuracy of energy performance forecasts and therefore, inappropriate investment decisions.

Through a case study, this paper presents a procedure for deriving and including the uncertainty associated with various factors in energy retrofit option assessment and clearly demonstrates how to generate probability distributions for final outcomes. These distributions provide decision makers with more insight into the risks associated with achieving the expected outcomes. The simulation process proposed in this paper could be used by modelers to improve the level of confidence associated with simulation outcomes and enhance the quality of investment decisions concerning energy retrofit.

An existing office building is selected and multiple calibrated energy base models are developed to evaluate a combination of lighting controls as a new energy retrofit option. The paper demonstrates the calibration process of the base models and a LCCA of the lighting controls package. A sub-analysis was conducted to examine how evaluating retrofit options with multiple base models could impact the financial outcomes and improve the final investment decisions. The financial metrics are compared with the results of modeling using a single base model. The results show that this approach could have the potential to and may alter a retrofit decision from 'no go' to 'go'.

It should be noted that the goal in this paper is not to generate the most accurate outcomes but to demonstrate a procedure to include risk and uncertainty in the energy modeling process of green retrofit technologies.

Introduction

As summarized by Bozorgi and Jones (2010), evidence suggests that there is inaccuracy/error associated with energy modeling forecasts and in some cases the models are not a good predictor of project energy performance (pp. 3/15-13/16). The accuracy of model prediction is greatly dependable on the accuracy of inputs. In the context of existing buildings, the level of uncertainty associated with simulation inputs is typically higher, because the systems may not performed as they specified or designed. Therefore, there is always some uncertainty associated with projecting the energy use based on design assumptions. It is critical for decision makers to consider the inaccuracy/error of modeling forecasts to avoid overestimating or underestimating the building energy performance when making decisions based on the predicted performance [1].

In this analysis, ranges and probability distributions are suggested to be used instead of single-point estimates in order to introduce various sources of uncertainty and articulate the risks associated with achieving the expected energy performance outcomes. Probability distributions are the primary quantitative vehicle used for explaining risk and uncertainty in the risk management analysis methods. All variables that are uncertain could be represented with probability distribution, and their associated risks could be estimated using statistical approaches based on specifications of a range of most likely values or extreme values. The variability of the expected return about its mean is used as a description of risk, and standard deviation is commonly used as a measure for spread of probability distribution. By providing more insight into risk, the proposed process will improve the reliability of energy modeling outcomes and also the confidence level of decision-makers in their decision-making process. As a result, the quality of investment decisions concerning energy retrofit options will increase [2].

Calibration of a base model is a critical part of the simulation process of existing buildings for the purpose of evaluating energy retrofit options. Existing buildings are typically modeled based on the necessary data and information obtained from available plans and construction details, specification books, and operating schedules. The results of initial simulations usually indicate that despite the careful attention in creating the models, the actual measured energy use is different from what was projected by models. This discrepancy is primarily due to the significant uncertainty or error associated with the simulation inputs, which this study attempts to explicitly consider in the simulation process. Mechanisms that are typically used to identify the errors and update the inputs include: using the most accurate as-built information, site visits, surveys and interviews with building operation managers and occupants, on-site measurement, such as outside air flow, temperature or light levels measurement, and checking the utility bills data, such as electricity bills and gas bills [3]&[4].

Accordingly, through conducting a case study on an existing office building, this paper aims to derive the various sources of uncertainty inherent in the energy retrofit analysis and numerically demonstrate a procedure for including those uncertainty factors into the modeling process in order to communicate more reliable outcomes to the decision-makers. The analysis shows how various potential risk and uncertainty might impact the final financial outcomes, and therefore, the investment decisions. The paper present a calibration process and explains how to create a reliable model to serve as a base case for evaluating the energy performance and generating distributions of energy performance indicators, resulting from selecting a new retrofit option—lighting controls package. It also describes a LCCA process of the selected retrofit option and demonstrates how to generate distributions of financial performance indicators such Net Present Value (NPV) and Internal Rate of Return (IRR).

Unlike the common practice of calibration, this study developed multiple acceptable base models for evaluating the selected energy retrofit option to account for inaccuracy of base models in generating the distribution of outcomes. Energy retrofit options are typically evaluated based on a calibrated energy base model. The acceptability of these base models are determined based on their forecasts error indicators. However, there might be several base models within the acceptable ranges that have different inputs, outputs, and error indicators. These base models could produce different outcomes when evaluating the performance of new retrofit options due to interactive modeling effects of retrofit options inputs. Thus, a sub-analysis was conducted to compare the estimated financial outcomes with the results of modeling using a single base model. The hypothesis here is that considering the inaccuracy of a base model could improve the level of confidence associated with simulation outcomes and enhance the quality of investment decisions regarding green retrofits. This analysis tests this hypothesis towards the broader goal of assisting decision-makers to make more informed decisions about investing in green retrofits. The results explain whether or not the impacts of modeling new retrofit options using different base models are significant enough to encourage modelers to put extra time and effort into running additional simulations.

It is important to note that this paper is mainly concerned with demonstrating the process of calibration and generation of distributions of outcomes and not the accuracy of final numeric results. The accuracy of outcomes is limited to the quality of assumptions and information that was obtained through literature, researcher's professional judgments, expert interview, and questionnaires.

Energy Simulation and Calibration Process

As mentioned earlier, a thorough calibration process requires on-site measurements, surveys and interviews with occupants, etc. However, in this case study, the model was made as reliable as possible based on the available drawings and interviews with the owner representative and the property manager. No measurement or experimental study was performed for collecting the actual data other than actual utility records. The subsequent steps were followed in order to arrive at a reliable model:

1) The initial model was set up in eQuest (QUick Energy Simulation Tool) based on the data collected from the architectural and mechanical drawings, construction details, researcher's visit, pictures, and interview with the owner representative who was also an occupant in the building. The annual and

monthly electricity consumptions were calculated based on the initial model. The building is all electric and there is no gas usage. A Typical Meteorological Year (TMY) file was used in the simulation process and not the actual weather file of 2009 for which the modeled consumptions was compared with. This could be one of the sources of inaccuracy associated with modeling outputs.

2) The actual annual and monthly electricity usage (KWh) was gathered by looking at 12 months of electricity bills in 2009. Adjustments were then made to those estimates in order to correspond to the calendar months. Utility records are not normally first of the month to last of the month, the simulation outcomes from energy modeling, however, are first of the month to last of the month. Two possible procedures for dealing with this include: if available, sum the daily simulation values to correspond to the measured records; or normalize the measured records to correspond to the simulated monthly values (weighted average approaches). This could be another potential source of inaccuracy associated with the modeling outputs. In this case, the weighted averages of actual electricity records were estimated to correspond to the calendar months.

3) The actual weighted average electricity usages were compared with those predicted by the simulation model, and the annual and monthly Mean Bias Error (EER) % and Coefficient of Variation of the Root-Mean-Squared Error (CV RMSE)—error indicators—were calculated by formulas presented in Equation 1:

$$\mathrm{ERR}_{\mathrm{month}}\,(\%) = \left[\frac{(M-S)_{\mathrm{month}}}{M_{\mathrm{month}}}\right] \times 100\% \qquad (1)$$

$$\mathrm{ERR}_{\mathrm{year}}\,(\%) = \sum\nolimits_{\mathrm{year}} \left[\frac{\mathrm{ERR}_{\mathrm{month}}}{N_{\mathrm{month}}}\right] \qquad (2)$$

where M: measured electricity (kWh) or fuel consumption; S: simulated electricity (kWh) or fuel consumption; N_{month}: number of utility bills in the year.

$$\mathrm{CV}\,(\mathrm{RSME}_{\mathrm{month}})\,(\%) = \left[\frac{\mathrm{RSME}_{\mathrm{month}}}{A_{\mathrm{month}}}\right] \times 100\%$$

$$\mathrm{RSME}_{\mathrm{month}} = \left\{\frac{\left[\sum_{\mathrm{month}}(M-S)^2_{\mathrm{month}}\right]}{N_{\mathrm{month}}}\right\}^{1/2}$$

$$A_{\mathrm{month}} = \left[\frac{\sum(M_{\mathrm{month}})}{N_{\mathrm{month}}}\right]$$

where RMSE: root-mean-squared monthly error; A_{month}: mean of the monthly utility bills.

Equation 1: EER and RSME formulas [4]

The calculated EER% and CV RMSE% were checked to see if they fall in any of the three accepted tolerances for data calibration suggested by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 14, International Performance Measurement and Verification Protocol (IPMVP), and Federal Energy Management Program (FEMP) (presented in Table 1)

Table 1: Acceptable tolerance for monthly data calibration

Index	ASHREA 14 (%)	IPMVP (%)	FEMP (%)
ERR month	±5	±20	±15
ERR year	-	-	±10
CV (RMSE month)	±15	±5	±10

Source: Pan, et al., 2007

The error percentages of the initial model did not agree well with the above acceptable ranges, and therefore, the initial model was not appropriate for evaluating the new retrofit options.

4) Further investigation was performed to collect more updated information about the inputs that might have higher impacts on the energy consumption and/or were not clear from the drawings—Information about current Heating, Ventilation, and Air-Conditioning (HVAC) and lighting systems including: types of cooling source; Roof Top Units (RTUs) zoning; HVAC schedule; thermostat set points for summer, winter, occupied, and unoccupied times; cold deck resets type and temperature; economizer system; lighting plans; desk lamps; and exterior lights and their schedules. Through a survey and a follow up interview with the property manager, most of the needed information was obtained and possible input changes were identified. For example, for thermostat set points which

have significant impacts on energy consumption, the property manager could not provide exacts values. She indicated that this has varied significantly in the past.

5) The initial model was calibrated and updated based on the new information from the property manager. The new modeling outputs (KWh) were compared with the actual usages by calculating error indicators—monthly and yearly EER as well as CV (RMSE). The new estimates were much closer to the acceptable ranges suggested by the aforementioned guidelines; however, they were still not within acceptable ranges.

6) The calibration process continued by varying the inputs, which were more uncertain based on our interviews and on-site visits, over reasonable ranges. The input changes included thermostat set points, lighting power density, task lighting and equipment power density, cold deck reset temperature, energy efficiency ratio (EER), minimum air flow, etc. More than 80 models were created and their calculated error indicators were compared with those suggested in Table 1. A model with error indicators that complied with the ranges suggested by FEMP and were very close to those suggested by ASHRAE 14 and IPMVP was selected as the best model. This calibrated model was thought to be sufficiently accurate to serve as a reliable base case for evaluating the new retrofit options. Table 2 shows the comparison of the energy consumptions predicted by this model and actual usages as well as related error indicators:

Table 2: Final Calibrated Model Error Indicators in Compare to Actual Electricity Usages

	Max	Min	Average
Measured 2009 Monthly Energy Use KWh	285181	153264	189703
Simulated Monthly Electric Use KWh	261700	151000	189708
EER month	8.23%	-13.32%	0.00%
Measured Total 2009 Energy Use KWh	2,276,431		
Simulated yearly Electric Use KWh	2,276,500		
EER year	0.00%		
CV (RMSE m)	6.79%		

Figure 1 shows the monthly electricity use as predicted by both the initial and final models. Through an iterative calibration process (creating and testing more than 80 models) the model was improved until they closely matched the actual consumptions. The EER_{year} of the best model was zero.

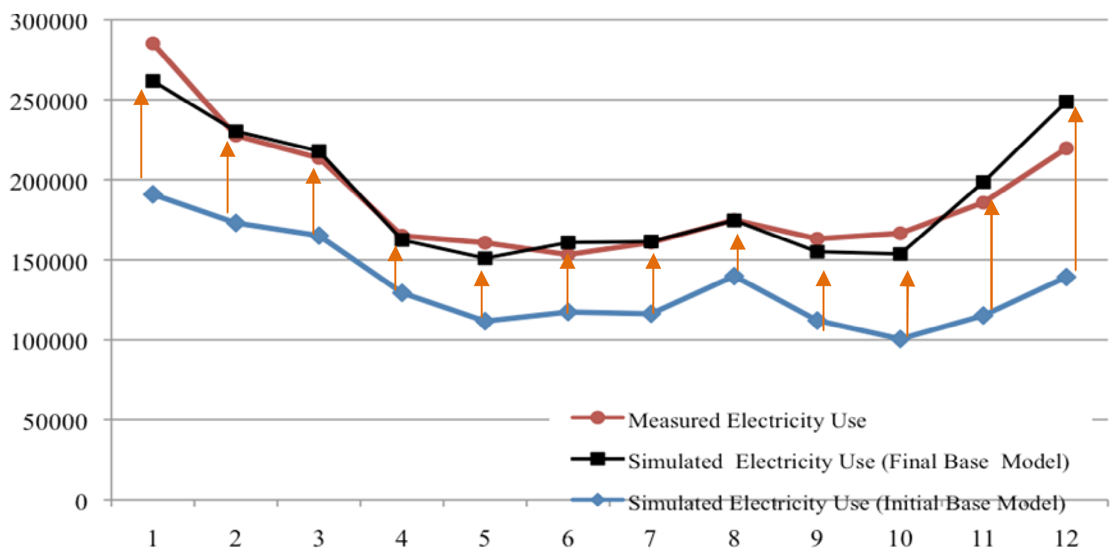


Figure 1: The eQuest Model prediction vs. actual consumption

7) The next step of the process was to model the retrofit option—lighting control systems—using the calibrated base model. The lighting control systems modeling, LCCA, and a procedure for generating the distribution of final financial outcomes are discussed in the following sections:

Final Distribution of Energy Savings and Interaction of Base Models

In current practice and literature, typically, a model that falls in any of the three accepted tolerances for data calibration stated in Table 1 and matches more closely with actual consumption—overall lowest monthly and yearly EER as well as CV $_{RMSE}$—will be used as a base model for existing buildings. New retrofit options will then be entered to this base model to be assessed and compared. However, base models themselves often involve a certain level of inaccuracy as they are typically calibrated based on the final modeling outputs, *which could be results of different inputs*. For example, the predicted energy consumption (KWh) of an energy model with certain assumptions about air conditioner Energy Efficiency Ratio (EER) and lighting power density could be very close to the one with a lower EER but a higher lighting power density assumptions. And both base models might be qualified as acceptable models, based on the aforementioned guidelines, due to their close predicted energy consumptions. In fact, this is very common in the calibration process as selecting a certain/accurate value for some inputs can be difficult in existing buildings.

Therefore, there might be several base models within the acceptable ranges that have different inputs, outputs, and error indicators. *A model with lowest error indicators is not necessarily the one that replicates the actual performance most accurately*, due to the uncertainty associated with inputs. Furthermore, selecting the lowest error indicators sometimes is not very straightforward, because a model might have a lower EER $_{month}$ for most of the months, but have a higher EER $_{year}$ or CV $_{RMSE}$. It is very important to note that while the final outputs (KWh) of acceptable models might be very close, they could produce different outcomes when evaluating the performance of new retrofit options. This is primarily due to interactive modeling effects of new retrofit options inputs with the base models. Therefore, ignoring the impacts of the variability of inputs for the base models on the outcomes might result in different investment decisions when comparing different retrofit options.

In summary, there are two factors that could influence the distribution/variance of savings associated with new retrofit options in the simulation of existing buildings: 1) ranges of assumptions for new retrofit options and 2) the inaccuracy of base models. In other word, as shown in Figure 2, the final simulation output distribution is the result of interaction between these two factors. In current practice and literature, the second factor, the inaccuracy of base models, is often ignored.

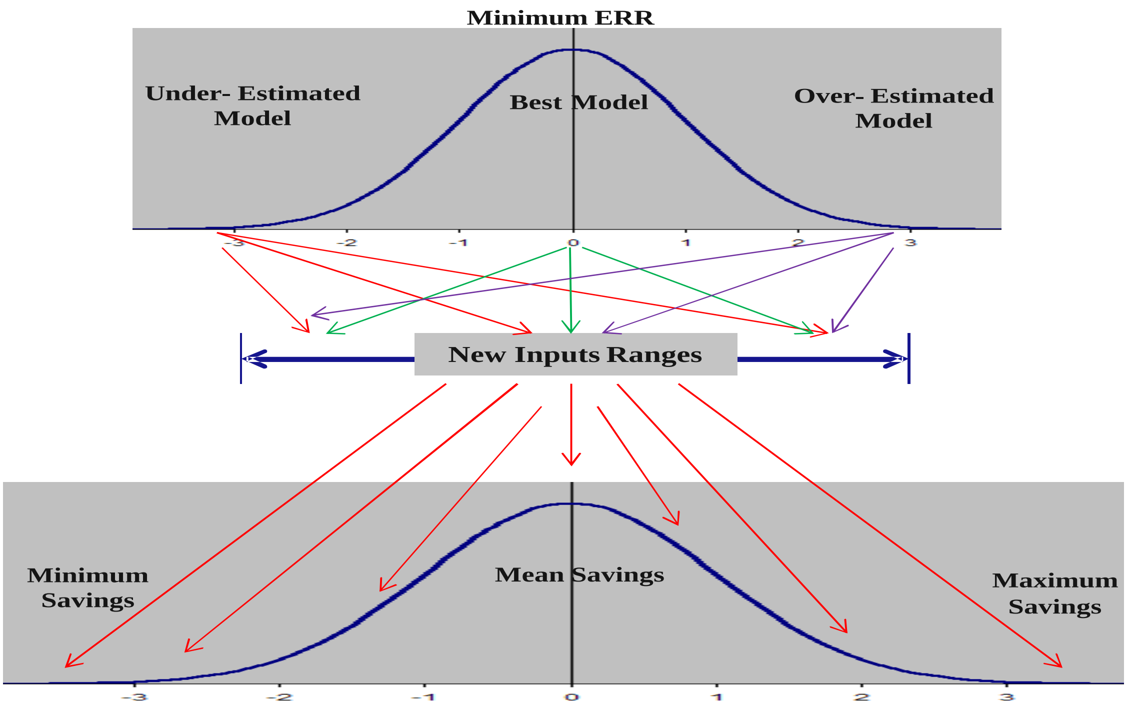


Figure 2: Interaction of base model inaccuracy in generating the final simulation outcomes

In this paper, lighting control systems were modeled with multiple base models to generate the distribution of energy savings and assess the potential impacts of different base models on simulation outcomes. The objective of this analysis was to understand how this approach could improve the final decisions about retrofit options investment and if the results were worth the effort of running additional scenarios. Might this approach alter the final investment decisions? This is one of the questions that this paper aims to address.

Creating Multiple Base Cases for Evaluating a New Retrofit Option

In order to create a more acceptable model, the seven inputs were selected to be varied over reasonable ranges. These inputs include: four thermostat set points (occupied cooling, occupied heating, unoccupied cooling, and unoccupied heating), cold deck reset temperature, EER of HVAC systems, and Variable Air Volume (VAV) minimum flow.

These factors were selected because, based on the interview with the property manager and researchers' professional judgments, they might involve a higher level of uncertainty. For example, relative to thermostat set points, the property manager indicated that set points have been varied significantly in the past. Thus, the set points values were selected as the inputs to be varied for creating other acceptable base models. Based on the mechanical drawings of the building, the EER values for two RTU units should be 15 and 14. However, this building was built in 2000, and it is likely that HVAC systems do not currently perform as efficiently as what they were designed for. Therefore, the EER values for two systems were varied in ranges of 12-15 and 11-14.

Several base models were created in addition to those built previously and their error indicators were calculated to ensure that they meet the acceptability conditions by the aforementioned guidelines. 22 models were within the acceptable tolerances. Figure 3 shows the distribution of the predicted yearly energy usages of the 22 base models:

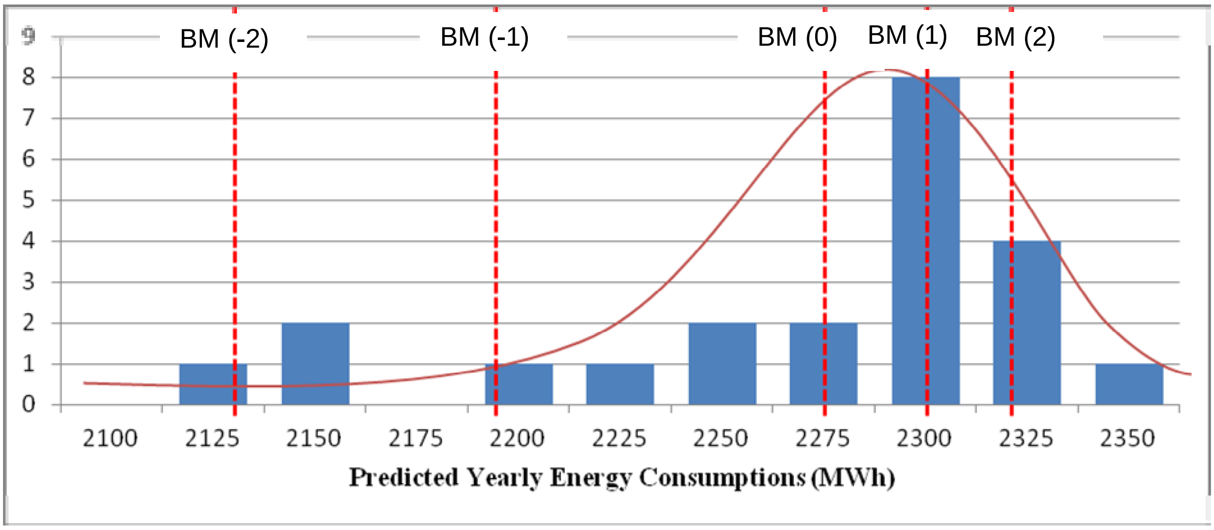


Figure 3: The Distribution of Predicted Energy Use (MWh) of 22 Base Models

As the distribution of energy consumptions shows, there are some base models (towards the left side) that under-predicted the energy consumption, compared to 2,276.5 MWh consumption of the best base model, and there are others (towards the right side) that over-predicted the consumption. The best model with EER_{year} of 0%, which is presented in Table 3, is close to the mean of the above distribution. Five base models (BM) were then selected from 22 models to be used for evaluating the lighting control option and generating the savings distributions. The five base models, BM (-2), BM (-1), BM (0), BM (+1), and BM (+2), are shown in Figure 3 by dash lines. BM (-2) denotes the base model with lowest predicted energy use, BM (0) the medium, and BM (2) the highest energy use. Their related assumptions, savings, and error indicators are presented in Table 3:

Table 3: Five base models assumptions, savings and error indicators

	BM (-2): Lowest prediction	BM (-1): Lower prediction	BM (0): Best Model	BM (+1): Higher prediction	BM (+2): Highest prediction
Yearly energy use prediction (MWh)	2,130.90	2,181.60	2,276.50	2,291.50	2,315.60
EER month	-4.1% to +14.3%	-8.7% to +11.6%	-13.3% to +8.2%	-14.3% to +6.9%	-13.8% to +7.7%
EER year	6.24%	4.06%	0.00%	-0.62%	-1.70%
CV (RMSE m)	9.03%	8.09%	6.79%	6.84%	7.14%

Accounting for Risks Associated with the Systems Performance - Five Cases for Lighting Control Systems Option

According to a principal at CQI Associate, energy models do not replicate the real world situation, "because those models do not take into account the true investment and cost issues and as well as experience-related issues about them. We have never seen the savings that high [as predicted by model]." There is a certain level of uncertainty associated with each technology which depends on the current level of knowledge of designers or contractors. How innovative is the technology? What is the proven and what is not proven? What are the standard practices versus more advanced practices?"

As mentioned previously, the primary goal of this paper is to present a procedure for including the uncertainty associated with various factors associated with lighting control systems into the modeling process and accounting for those inherent experience-related risk issues in the modeling outcomes. The result of the analysis shows how various potential risk and uncertainty might impact the final financial outcomes, and therefore, the investment decisions. There are several risks associated with the actual performance of lighting control systems. Daylight sensors need to be well calibrated to perform as they are designed, otherwise there might be no savings and low satisfaction by occupants. Occupancy sensors may not be as effective as they are expected to be, if not located properly to cover the area under their control. There is always a risk of poor quality of installation or workmanship—the contractors' risk. Therefore, in order to demonstrate a process of accounting for the potential risks associated with the performance of the lighting retrofit option in the modeling process, five different cases were developed. Seven factors/variables related to lighting controls performance were identified and their values were varied over defined ranges for creating the five lighting retrofit cases. Case 1 was the best case, case 3 was the most-likely, and case 5 was the worst case. Defining a range for each variable would help to account for some of the risks associated with the option's performance. If a retrofit option is an innovative technology that the market does not have much experience with, the wider ranges might be defined for its uncertain variables. If it is a proven technology, like the lighting retrofit option in this case, the ranges could be narrower accordingly. Table 4 shows the variables and their values for each lighting control system case:

Table 4 : Variables and Range for Creating Five Lighting Controls Cases

Variables	Case 1	Case 2	Case 3	Case 4	Case 5
Minimum Light Level – Daylight Sensors	5%	5%	10%	10%	20%
Occupancy Sensors (Schedule)	Low	Low-Medium	Medium	Medium-High	High
High End Tuning Strategy	21.0%	20.5%	20.0%	19.5%	19.0%
Personal Dimming Control	17.0%	16.0%	15.0%	14.0%	13.0%
Lighting Power Density (W/Sq.Ft)	1.1	1.3	1.5	1.5	1.6
Demand (KW) Prediction Adjustment Factor	0.8	0.86	0.92	0.96	1

The minimum lighting level or the minimum output fraction for continuous control type, which is the lowest lighting output that the lighting system can dim down to, is expressed as a fraction of maximum light output. This is the fractional light output that the system produces at a minimum input power. Lutron Electronics claims that their sensors could dim down to 1%, however, daylighting was modeled with systems with minimum lighting level of 5%, 10%, and 20% to account for the potential risks, mentioned above. Occupancy sensors are modeled with different occupancy schedules, low to high. In the high end tuning strategy, typically the digital ballasts would be set to trim 20% on top of the lighting output. Therefore, a range of 19%-21% trimming was considered. Studies by Lutron Electronics showed a 15% lighting energy savings when personal dimming controls were employed. A saving range of 13%-17% was considered for personal dimming controls to account for uncertainty associated with its related savings. Lighting power density is one of the factors that could have a significant impact on the outcomes of lighting control systems. Also, it could vary significantly based on the occupants' behavior. Since no tests were conducted in this case study to measure the actual lighting power density, a range of 1.1-1.6 (W/Sq.Ft) was considered to account for this variance. Demand reduction is one of the important benefits of lighting control systems such as daylight sensors. The demand peak (KW) reduction of this option was estimated through eQuest. As described previously, the energy based models in this study were calibrated based on KWh consumptions, so that the predicted KWh matches the actual KWh. They were not calibrated based on their KW prediction. The predicted KW of the best base model (BM0) was compared to the actual values. The EER_{year} was 13.61%. This indicates that the BM0 was over-predicting the annual demand peak by 13.61%. Therefore, in order to account for this inaccuracy in energy models, a multiplier, in a range of 0.8-1, was considered to adjust the KW prediction in each case.

The five lighting retrofit cases, described in Table 4, were modeled using the five base models, explained in Table 3 through eQuest, which result in a total of 25 energy models/savings estimates. These 25 estimates are used to generate the distributions of energy savings and related financial performance indicators. An excel-based model, a Lighting Control Systems Analytics (LCSA) was then developed for estimating the final lighting controls energy savings and performing economic analyses for each case. This is an analytic tool that could take the KWh and KW estimates from energy models as inputs, and perform a comprehensive analysis to estimate energy savings and financial performance indicators such as simple payback, simple ROI, NPV and IRR as outputs. The assumptions for creating the five lighting cases are primarily based on the researcher's professional judgment and experts' interview. They may not be the most accurate assumptions as no measurement tests or tenants interviews are performed in this case study. As mentioned previously, the goal is not to generate the most accurate outcomes but to demonstrate a procedure to include risk and uncertainty in the energy modeling process of green retrofit technologies.

Distributions of Energy Performance Indicators and Total Energy Cost Savings

In order to estimate the distributions of energy performance indicators, 1) the impacts of daylight harvesting, occupancy sensors, and different lighting power density on energy savings were first calculated by modeling the 25 cases (five cases by five base models) in eQuest; 2) The outputs, including KWh and KW estimates for both lighting and whole building, were taken to the LCSA; 3) The impacts of high-end trimming[1], personal dimming control, and demand peak adjustment factors were then estimated and incorporated through the LCSA; and 4) The distributions of energy performance indicators, KWh savings and KW savings, were generated based on the 25 saving estimates. Figure 4 and Figure 5 show the distributions of total MWh and KW savings:

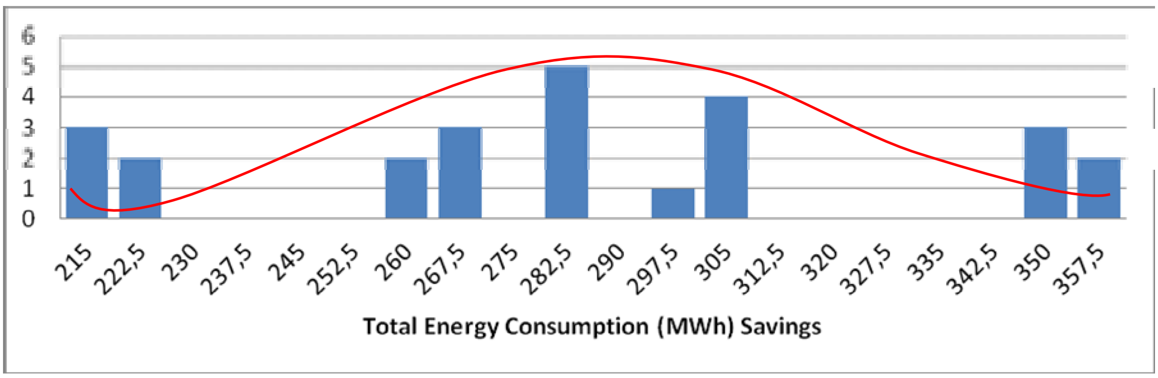


Figure 4: The Distribution of Energy Consumption Savings (MWh)

[1] High-end trimming/tuning: sets the maximum light level based on customer requirements in each space.

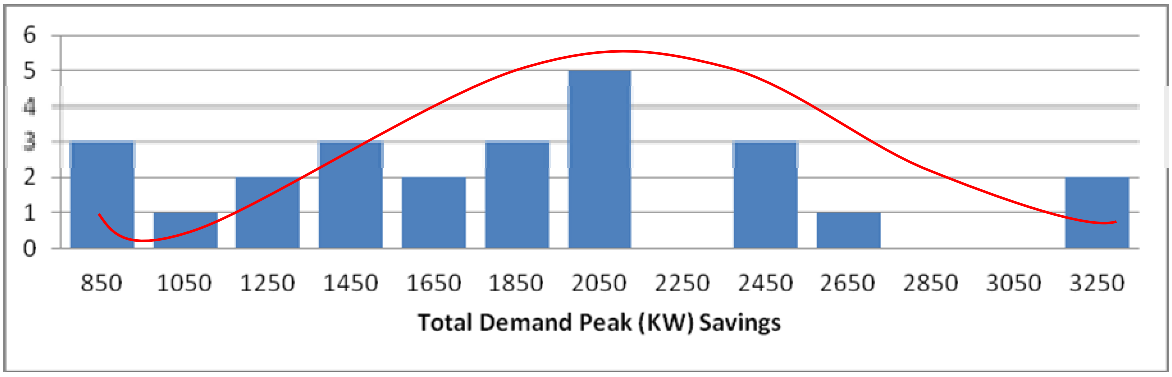


Figure 5: The Distribution of Peak Demand Savings (KW)

Based on the annual KWh and KW savings and electricity costs per KWh and KW, the total cost savings were estimated for the 25 cases. The summary of statistics of total costs savings are presented in Table 7.

Financial Analysis

Simple Cost-Based Analysis

The entire capital costs data for lighting control systems including equipment and installation costs were obtained from Lutron Electronics. Capital costs could vary significantly based on the building characteristics, number of existing lighting fixtures, users' expectations, lighting contractors, etc. For the purpose of this analysis, five capital cost estimates were developed for the lighting retrofit cases 1-5 to account for the potential uncertainty associated with cost approximation suggested by Lutron Electronics. The utility provider for the building provides incentives for lighting equipment replacements / retrofits and lighting control systems. It pays all incentives four weeks after the project completion and verification. Thus, the total incentives for the lighting control systems were estimated for the five cases based on assumed ranges for numbers of sensors and ballasts and amount of the incentives for each installation.

Since the incentives are more likely to be paid in the same year that lighting retrofits occur, the total investment/development costs of the lighting retrofit option were then estimated by subtracting the incentives from the total capital costs. Table 5 shows the capital costs, the total utility incentives, and the total investment costs for the five cases.

Table 5: Capital Costs, Utility Incentive, and Investment Costs

Descriptions	Case 1	Case 2	Case 3	Case 4	Case 5
Total capital costs	$329,430	$342,785	$356,140	$365,044	$373,947
Total utility incentive	$50,824	$54,487	$63,172	$75,402	$93,487
Total Investment/Development Costs	$278,605	$288,298	$292,968	$289,642	$280,460

Simple paybacks and simple Return On Investment (ROI) were estimated using the total investment/development costs and total cost savings, and their distributions were generated based on the 25 savings cases. The summary of statistics are presented in Table 7

Life Cycle Cost Analysis (LCCA)

Cash flows for a period of 20 years were developed. NPVs and IRRs were estimated over four time horizons of 5, 10, 15, and 20 years to show the financial performance of the lighting retrofit over various life cycles. The costs of lighting replacements at the end of their useful life cycle were included in the cash flows for two conditions. The two conditions are 1) When a lighting retrofit option is undertaken and new control systems are installed— the replacement costs can negatively impact the cash flow at the end of the new systems useful life 2) When no lighting retrofit is undertaken and existing lighting fixtures will be replaced with similar models—the costs can positively impact the cash flow at the end of the remaining useful life of the existing lighting fixtures. Table 6 shows the certain assumptions that are made for performing the LCCA:

Table 6: Assumptions for LCCA

	Case 1	Case 2	Case 3	Case 4	Case 5
Discount Rate for LCCA	7.0%	7.5%	8.0%	8.5%	9.0%
Reduction in maintenance cost for first X years (until the end of UL)	$1,000	$900	$800	$700	$600
Remaining useful life (UL) of current lighting fixture	3	4	5	6	7
Total cost of upgrade current non-efficient fixture at the end of UL/Sq.Ft	$0.80	$0.90	$1.00	$1.10	$1.20
Capital cost for replacing the current lighting fixture at the end of their UL	$71,228	$80,132	$89,035	$97,939	$106,842
Useful life of new lighting control systems and fixtures from Lutron	15	14	13	12	11
Capital costs of upgrading new lighting systems after the first useful life (first 10-15 years)	$160,263	$169,167	$178,070	$186,974	$191,425

Distributions of NPVs and IRRs over various periods of 5, 10, 15, and 20 years were generated. Table 7 shows the minimum, maximum, mean, and standard deviation of financial outcomes:

Table 7: Min, Max, Mean, and Standard Deviation of Financial Outcomes

Financial Metrics	Min	Max	Average	Standard Deviation
Total $ Savings	$26,975	$49,829	$38,163	$6,656
Simple Paybacks	5.6	10.4	7.7	1.4
Simple ROI	9.62%	17.89%	13.35%	2.41%
5-Year NPV	($152,667)	$22,199	($78,550)	$61,199
10-Year NPV	($28,430)	$225,171	$97,429	$68,462
15-Year NPV	($3,390)	$334,067	$150,239	$101,059
20-Year NPV	$53,661	$478,213	$249,254	$129,192
5-Year IRR	-23%	11%	-8%	12%
10-Year IRR	9%	27%	17%	5%
15-Year IRR	9%	29%	18%	6%
20-Year IRR	12%	30%	20%	5%

Interpretation of Distributions of Final Outputs

Probability distributions provide information about the probability of achieving the estimated outcomes. Based on the empirical rule if a distribution is approximately normal then the probability is about 68.26 percent of the estimates will lie within one standard deviation of the mean (mathematically, • ± • , where • is the arithmetic mean), about 95.44 percent will be within two standard deviations (• ± 2•), and about 99.74 percent will lie within three standard deviations (• ± 3•) [3].

The distributions of NPVs in this scenario are approximately normal, and therefore, the following information could be understood from the distribution of average 5-year NVP:

- There is about 68% chance that the 5-year NVP falls between -$139,749 and -$17,351.
- There is about 95% chance that the 5-year NVP falls between -$200,948 and +$43,848.
- There is about 99.5% chance that the 5-year NVP falls between -$262,147 and +$105,047.
- There is less than 13% chance that the 5-year NVP is positive.

- There is about 84%chance that the 5-year NVP is not less than -$17,351.
- There is about 2% that that the 5-year NVP is higher than +$43,848

The above information provides investment decision-makers with more insight into risk associated with achieving the expected financial outcomes. As a result, decision-makers would be able to make more informed decisions concerning investing in green retrofit options.

Discussion on Using Multiple Base Models for Simulating Retrofit Options

The hypothesis here is that considering the inaccuracy of a base model in the modeling process could improve the level of confidence associated with simulation outcomes and enhance the quality of investment decisions regarding green retrofits. This sub-analytic attempts to test this hypothesis towards the broader goal of assisting decision-makers to make more informed decisions about investing in green retrofits.

In order to measure the impacts of simulation with multiple base models on financial outcomes, the low-end and high-end impacts were estimated by comparing the minimum and maximum of each financial outcome to related average value of the best model (BM0). The assumption was that the retrofit options would be modeled using the best model (BM0), if multiple base models would not be used. Table 8 shows the impacts, both absolute values and percentages, on different financial indicators:

Table 8: Impacts of simulating by multiple base models on financial outcomes

Financial Indicator	(Min - BM0)	(Max - BM0)	Low-End Impact	High-End Impact
Total $ Savings	-$744	$3,563	**-2%**	**13%**
Simple Paybacks	-1.2	0.2	**-12%**	**2%**
Simple ROI	-0.3%	1.3%	**-2%**	**13%**
5-Year NPV	-$3,596	$16,625	**-38%**	**136%**
10-Year NPV	$0	$65,771	**0%**	**253%**
15-Year NPV	-$9,181	$39,206	**-334%**	**2708%**
20-Year NPV	-$11,334	$46,742	**-10%**	**79%**
5-Year IRR	-1%	4%	**-17%**	**74%**
10-Year IRR	-1%	2%	**-3%**	**25%**
15-Year IRR	-1%	3%	**-4%**	**32%**
20-Year IRR	-1%	2%	**-2%**	**20%**

Therefore, if the lighting controls option was only modeled using one calibrated base model:

- The total savings could have been underestimated by 13% ($3,563) or overestimated by 2% ($744).
- The Simple Payback could have been underestimated by 2% (0.2 year) or overestimated by 12% (1.2 years).
- The 5-year NPV could have been underestimated by 136% ($16,625) or overestimated by 38% ($3,596).
- The 5-year IRR could have been underestimated by 74% (4%) or overestimated by 1% (17%).

The results of the analysis show that including inaccuracy of base models could have the potential to impact the financial outcomes and influence the investment decisions. There were few conditions in the NPV analyses, 10-year and 15-year NPV, where one case has a negative NPV with the best case (BM0) but positive NPVs with other base models. Thus, if an investor bases her/his decision on the result of modeling with a single base model, she/he would not agree to invest in the lighting controls option. The 4% increase in a 5-year IRR or $16,625 in a 5-year NPV could alter an investment decision from ‘no go’ to ‘go’.

It should be noted that many factors might play roles in the magnitude of impacts. Factors include level of calibration, type of retrofit options, investors return' horizons, building characteristics, or nature/level of analysis. Accordingly, the inaccuracy of base models could potentially impact the investment decisions at the property level, when selecting the retrofit options. It could alter an investment decision from 'no go' to 'go'.

Conclusion

Decision-makers often rely on the results of the energy simulation when making investment decisions about energy retrofit options. Thus, it is important for modelers/consultants to examine potential strategies to improve the reliability and level of confidence associated with simulation outcomes to ultimately enhance the quality of investment decisions. Towards achieving this objective, this paper presents how to define and include ranges for uncertain factors in the energy retrofit assessment process and explains how to generate distributions of outcomes to communicate risk associated with achieving the expected outcome. The proposed process is numerically demonstrated through a case study on evaluating a combination of lighting controls package for an existing office building.

When simulating a new retrofit option in an existing building, there are two factors that could influence the distribution/variance of savings associated with the retrofit option: 1) ranges of assumptions for new retrofit options and 2) the inaccuracy of base models. The final simulation output distribution is the result of interaction between these two factors. In current practice and literature, the second factor, the inaccuracy of base models, is often ignored. The analysis shows that considering the inaccuracy of a base model in the modeling process could improve the level of confidence associated with simulation outcomes and enhance the quality of investment decisions regarding green retrofits. It could alter an investment decision from 'no go' to 'go'. However, the result of this single analysis cannot be generalized. Therefore, depending on the level of analysis, modelers are encouraged to consider the inaccuracy of a base model in addition to the uncertainties associated with each retrofit option when making investment recommendations about green retrofits to decision-makers.

References

[1] Bozorgi, A., & Jones, J. R. (2010). *A Procedure for Linking Projected Energy Performance Uncertainty with Investment Decision-Making.* Proc. of ACEEE Summer Study, Pacific Grove, CA.

[2] Bozorgi, A., & Jones, J. R. (2010). *A Framework for Estimating and Communicating the Financial Performance of Energy Efficiency Improvements in Existing Commercial Buildings While Considering Risk and Uncertainty.* Proc. of IEECB'10, Frankfurt, Germany.

[3] Pan, Y., Huang, Z., & Wu, G. (2007). *The Application of Building Energy Simulation and Calibration in Two High-Rise Commercial Buildings in Shanghai*. Energy & Buildings 39(6), 651-657.

[4] Westphal, F. S., & Lamberts, R. (2005). *Building Simulation Calibration Using Sensitivity Analysis*. Proc. of the Ninth International IBPSA Conference, Montreal, Canada.

[5] Ott, R. L., & Longnecker, M. (2001). *An Introduction to Statistical Methods and Data Analysis* (5th ed.): Duxbury.

The role of office users in the sustainability of office buildings – an empirical investigation and implications for FM

Lukas Windlinger[1]

Marcel Janser[1]

Annika Feige[2]

Holger Wallbaum[2]

[1] *School of Life Sciences und Facility Management, Institute of Facility Management, Zurich University of Applied Sciences, Switzerland*

[2] *Institute for Construction Engineering and Management, Chair of Sustainable Construction, Swiss Federal Institute of Technology Zurich, Switzerland*

Abstract

Energy consumption in office buildings depends on energy efficient construction and technology, but is also significantly affected by occupant behavior and facilities management practices. It is not clear, however, which reasons account for occupant energy consumption and what measures can be taken to realize latent energy saving potentials.

The aim of this study consists in the analysis of causes of energy-inefficient occupant behavior and thus to provide background information for organizational measures targeted at the reduction of energy-consumption. In the present study we investigated these questions by asking office occupants about (a) their energy related behavior, (b) reasons for suboptimal energy related consumption and (c) their knowledge of energy efficient behavior in office buildings.

1174 occupants working in 12 office buildings participated in an online survey. The results show that up to 20 per cent of occupants report bringing personal electronic devices to the workplace. Around 10 per cent of the occupants have manipulated ventilation ducts in their work area in order to optimize their comfort. The study shows that the main reasons for not acting energy efficiently are not attitudes or goals. They relate to a lack of information, lack of incentives, and habits. This finding is further supported by the survey participants' statements about the three most effective actions occupants can take to reduce energy consumption in the building. The most cited action taken by respondents to reduce energy consumption was to switch off lights when they were not required. There were a number of more effective energy efficiency measures that were not cited frequently (such as reducing heating), indicating a lack of awareness.

It is recommended that organizations implement awareness and feedback systems tailored to organizational practices in order to change occupant's habits. FM departments should take the responsibility of analyzing energy-related occupant behavior and of leading projects to increase energy-efficiency and sustainability in organizations.

Introduction

Buildings in use can be considered as systems composed of technology, design, and users. In the current discussion on sustainable building, there's a strong emphasis on energy efficient construction and technology. The role of end-users' behavior has largely been overlooked [1, 2]. Facility activities cause more than 50 per cent of the overall environmental impact in service organizations [3]. These activities are targeted at end-users of the buildings or influenced by them. Occupant behavior and facility management practices therefore play a crucial role in promoting energy efficiency and reducing the carbon footprint of workplaces. This perspective is substantiated by the fact that the actual energy consumption of office buildings is often much higher than initially planned and predicted [4]. According to previous studies it can be assumed that 20 per cent of energy consumption in office buildings can be saved without any loss in occupant comfort [5]. It is not clear, however, what accounts for this apparent disparity and what measures can be taken to realize these latent energy saving potentials. Furthermore, much energy-related behavior may be associated with comfort, and therefore conflicts between occupant requirements for comfort and energy consumption may arise.

The focus of this study is the comfort of workplace occupants, and their energy related behavior. The aims of the paper are fourfold: (a) aspects of occupant behavior relevant to workplace energy consumption is analyzed; (b) reasons for energy-inefficient behavior explored; (c) occupant knowledge of energy efficient behavior in office buildings examined; (d) these analyses are related to individual-level theoretical models of energy-conscious behavior, and theoretical and practical suggestions are discussed.

Theoretical background

Research on energy-saving or sustainable behavior has focused on individual motivations rather than contextual factors [6]. An influential theoretical framework guiding much of this research is the Theory of Planned Behavior [7]. This theoretical framework is based on the assumption that human action generally is based on reasoned choices among behavioral alternatives in order to attain the highest benefits and lowest costs. These behavioral intentions themselves are influenced by both, one's attitude toward certain types of behavior, and a subjective value-based assessment of social and moral norms, i.e. the perceived social pressure to perform a behavior. In addition to the two components referring to attitudes and values, the degree of perceived behavioral control affects the intention to perform certain types of behavior. Perceived behavioral control refers to the perceived ease or difficulty of performing the behavior, i.e. contextual factors that facilitate or constrain intended actions. While the Theory of Planned Behavior has been successful in explaining various types of environmental behavior [6], it is still a subject of debate; especially the basic assumption of a strong attitude-behavior relation is discussed from an empirical-methodological point of view (e.g. [8]) as well as from a theoretical perspective (e.g. [9]). At the core of these discussions is the observation that general attitudes do not predict specific behaviors. Lindenberg and Steg [9] acknowledge that behavior results from different and multiple motivations that may be more or less in the focus of an individual in different situations. It is, however, not clear which characteristics of a situation will trigger a certain motivation, or set of motivations. Furthermore, different motives may conflict with each other. For example, an office user's primary goal will normally not be to save energy. Saving energy constitutes only one objective among a set of others (such as increasing one's comfort, for example). The study of energy-relevant behavior in office buildings and the context of business practice therefore requires the extension of a theoretical framework such as the Theory of Planned Behavior. In addition to attitudes related to energy-conservation, the following factors influence efficient or inefficient environmental user behavior in office buildings: habits [6]; self-efficacy for energy-saving behaviors (i.e. the evaluation of a person of whether he/she has the necessary resources, knowledge, and/or skills to reach a specific goal [2]); information about energy-saving options in the building [10]; incentives [11]; and goal conflicts [9].

Furthermore, building and organization specific factors (i.e. contextual aspects) may facilitate or constrain office building users' energy-related behaviors. Organizational and building related determinants of environmental behavior can be analyzed through the comparative study of buildings and organizations [2].

Methods

The data presented in this article has been collected from a current Swiss research project called "Quality of sustainable buildings – The impact of sustainable buildings on comfort, well-being and productivity". The project combines surveys of office users, interviews with facilities managers, and physical and chemical analyses of indoor environment quality. Data was collected in winter 2011/12 and summer 2012. The data presented here has been collected during winter 2011/12, and includes 12 office buildings of five organizations (financial and energy industry; construction and engineering consultancy). The sample of buildings is based on the voluntary participation of organizations, and as such can be described as an ad hoc sample. However, the buildings that are studied have been chosen by organizations and the research team together in order to ensure that typical office building rather than extreme ones are analyzed. The study is therefore limited to private sector office buildings with at least 100 workstations per building. Buildings with major renovations in the past two years were excluded from the study. Two of the twelve buildings have a Minergie energy-efficiency certificate (a Swiss quality label for low-energy-consumption buildings).

A total of 1174 office users (40 per cent female, 60 per cent male; median age 37) participated in the survey out of 3693 invited making up a response rate of 32 per cent.

Participants also represent an ad hoc sample and the employees that were invited to participate have been selected by organizations and the research team in order to invite typical office users. The office user survey was conducted in an electronic on-line format and participants were informed and invited to participate by e-mail.

The questionnaire contains about 170 questions. The items relevant for this article concern reasons for energy-inefficient behavior, aspects of occupant behavior relevant for energy consumption, and users' knowledge on energy efficient behavior in office buildings. These items were developed for this research. The questionnaire includes 12 questions regarding the six aspects of energy-inefficient occupant behavior:

- Attitudes towards saving energy include 2 items (e.g. "I don't consider energy conservation to be that desirable").
- Energy-consumption habits were assessed by the users on 1 item: "Sometimes one just doesn't think of the own energy consumption and therefore wastes energy unintentionally".
- Self-Efficacy regarding energy saving behavior was assessed on 3 items (e.g. "Saving energy is useless because the other building occupants are not committed to energy conservation").
- Information was assessed on 1 item: "I'm insufficiently informed about my opportunities to save energy in our building".
- Incentives regarding energy conservations include 2 items (e.g. "Our company insufficiently rewards energy conservation").
- Goal-Conflicts were assessed on 3 items (e.g. "Saving Energy is not compatible with good work-efficiency").

The internal consistency of multi-item scales was assessed using Cronbach's alpha. The values range from .67 to .74 and are satisfactory [12].

The questions related to aspects of occupant behavior relevant for energy consumption refer to the use of personal electronic devices brought to the workplace by users (e.g. heaters or fans) and to modifications of the work environment (e.g. cover / block / seal / divert ventilation ducts).

Information concerning respondent awareness of effective actions to reduce energy consumption in workplaces was collected with a set of open questions, where survey participants were asked to name the most effective, second most effective, and third most effective action they knew.

Results

The results of the study are presented in three sections. First, the overall results from the occupant survey are presented. Second, these results are compared between buildings. Third, they are compared between participating organizations.

Energy-relevant behavior

Occupants were asked whether they used personal electronic devices and other equipment and if they had ever manipulated the building in order to increase their level of comfort. A total of 577 survey participants (53%) responded that they had used at least one) of the appliances proposed in the survey and/or had manipulated a feature of the work environment. Figure 1 shows the results for the electric devices brought into the offices and used by the building occupants.

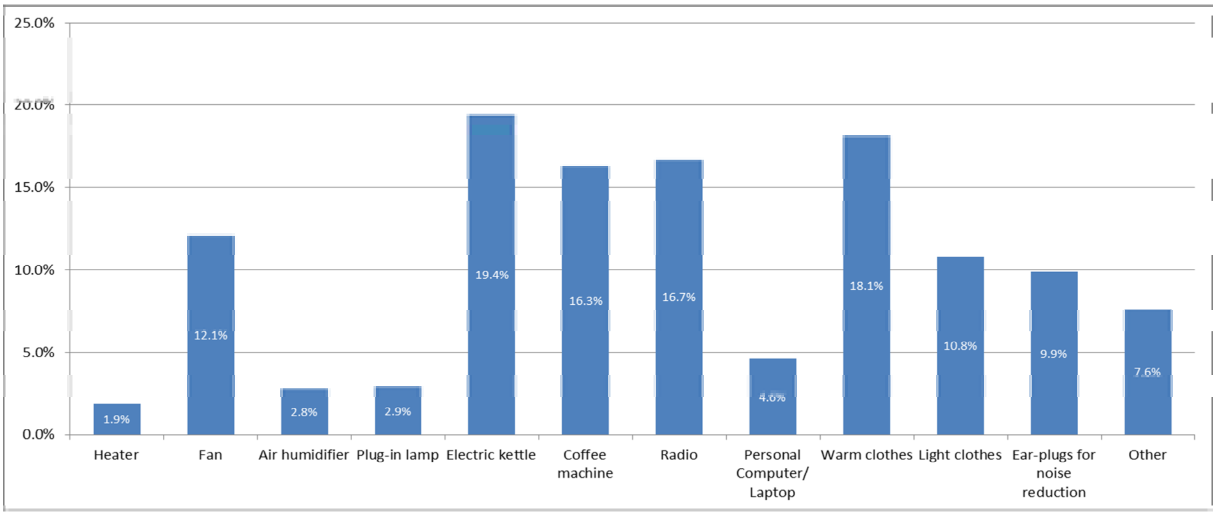


Figure 1: Percentage of occupants using personal electric devices/ special equipment in order to increase their comfort at work

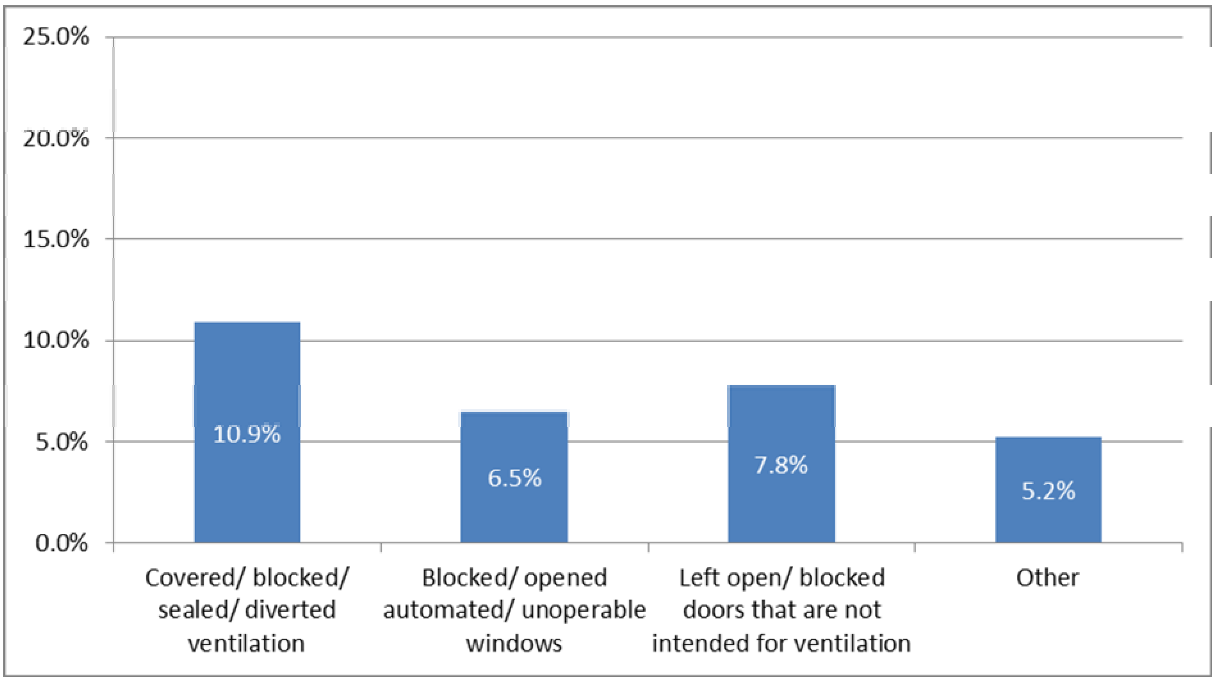


Figure 2: Percentage of occupants who have ever carried out different building manipulations in order to increase their comfort

The most common devices brought to workplaces by occupants were: kettles; warm clothes; radios; and coffee machines. Building-related manipulations in the work environment are presented in figure 2. 237 out of 1025 (23 per cent) participants who had answered this question indicated that they had altered some feature of their environment. More than 10 per cent said that they had covered, blocked, sealed, or diverted ventilation ducts. 6.5% and 7.8% respectively stated that they had blocked or unblocked windows or doors. Furthermore, 5.2% indicated that they had carried out other manipulations such as removing electric bulbs or moving to a different workstation.

Reasons for energy-inefficient behavior

Occupants were also asked for reasons why their behavior may be energy-inefficient or suboptimal. The results are displayed in Figure 3. Building users indicate that conflicting habits, lack of information, and lack of incentives are the most important reasons for suboptimal behavior. Attitudes, self-efficacy, and conflicting goals were found to be less important. A univariate analysis of variance (ANOVA) shows that the differences in the reasons are statistically significant (F (11, 12934) = 140.18, p = .000).

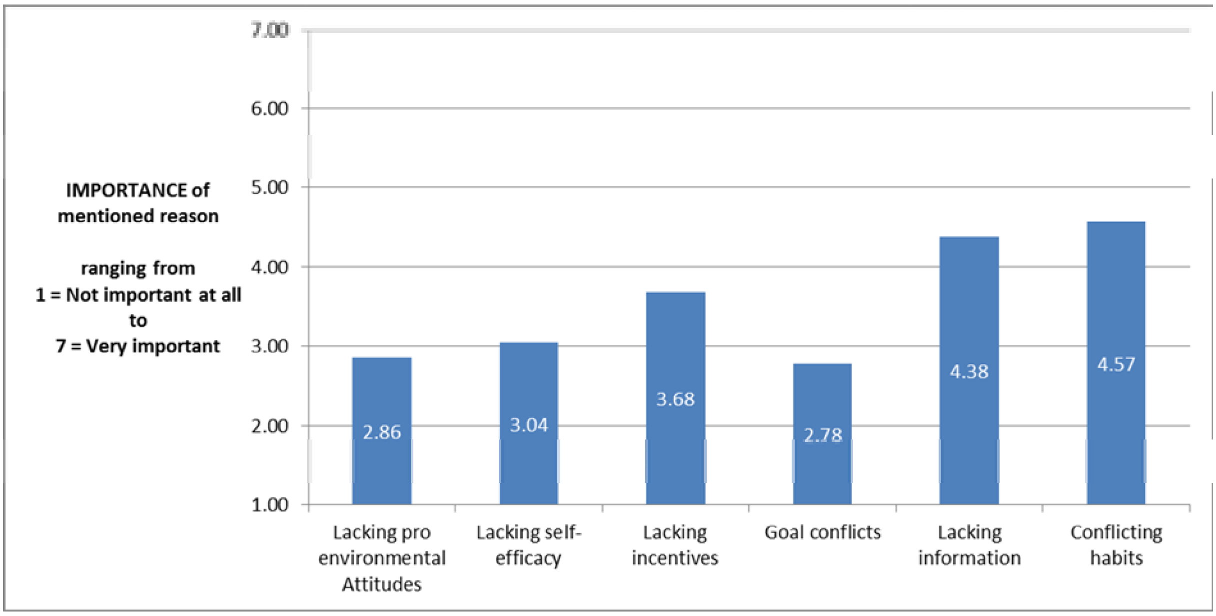


Figure 3: Perceived importance of reasons for energetically suboptimal behavior

Occupant knowledge on energy-efficient behavior

Occupant knowledge on energy-efficient behavior was measured with three open ended questions asking participants for the three most effective actions that users can take in order to reduce energy consumption in the building. Thematic clustering of all answers resulted in 12 categories with at least 20 entries (shown in figure 4). With regard to the response rate there were many participants who skipped one or two or even all of the three questions (response rate was 70%, 62%, 48%, respectively). At the same time there were also several participants who mentioned more than one action per question. This explains why the number of actions coded doesn't match the number of possible data entries.

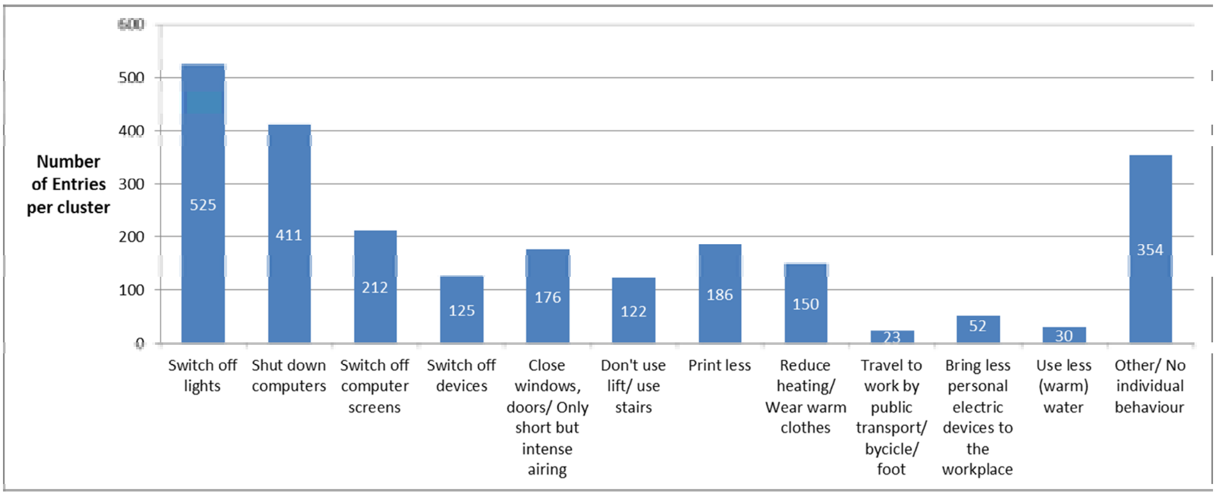


Figure 4: Occupant knowledge on energy-efficient behavior

The actions that were mentioned most frequently were switching off lights when leaving a room (525 entries) and shutting down computers in the evening (411). Switching off computer screens specifically (212) and devices in general (125) were also quite frequently mentioned and so was the idea to bring less personal electric devices to the workplace (52). In addition there were also entries that were not related to the direct but rather to the indirect use of energy such as: building related actions (close windows and doors/ short but intense airing: 176; reduce heating/ wear warm clothes: 150); transport related actions (don't use lift/ use stairs: 122; travel to work by public transport/bicycle/ foot: 23); and resource related actions (print less: 186; use less (warm) water: 30).

Comparison of energy-relevant behavior across buildings and organizations

The comparison of energy-relevant behavior, as well as of the reasons for suboptimal behavior, across buildings and organizations reveals that there are significant differences. Figure 5 and 6 illustrate these differences between buildings and organizations for the use of (personal) fans and manipulating ventilation ducts respectively.

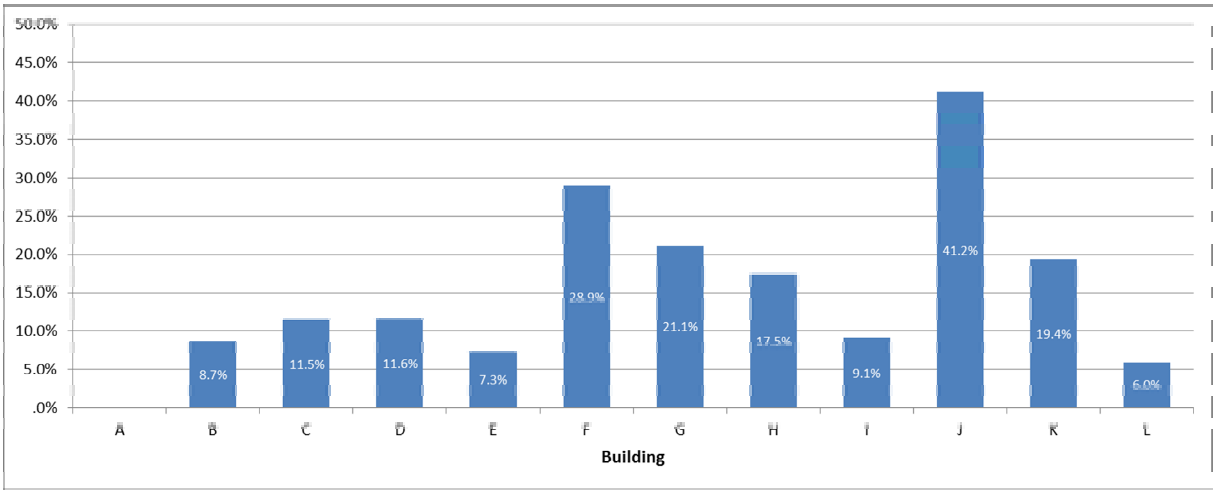


Figure 5: Percentage of occupants using a personal fan per buildings

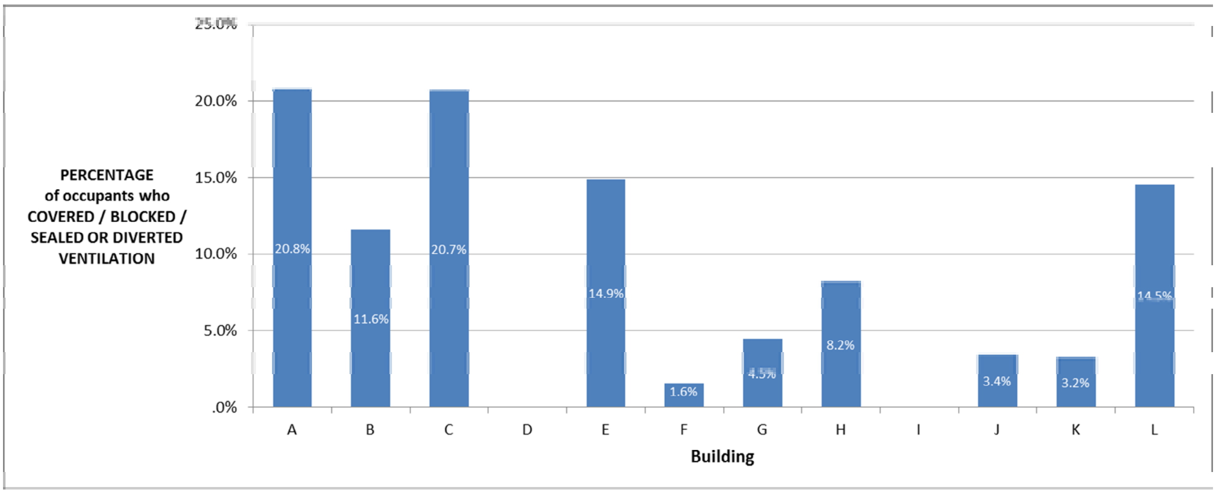


Figure 6: percentage of occupants who manipulated ventilation ducts per building

In contrast to energy-relevant behavior, the reasons are more similar across buildings: There are significant differences in attitudes, self-efficacy, and information. For habits, incentives, and conflicting goals there are no significant differences between the buildings studied. The differences follow a clear pattern: in buildings where users think their attitudes are strongly pro-environmental, they also report higher self-efficacy and higher levels of information about energy saving opportunities in their buildings. Similar to differences between buildings, there are significant differences between organizations (figure 7 and 8). These results indicate that there are strong influences by organizational policies and practices.

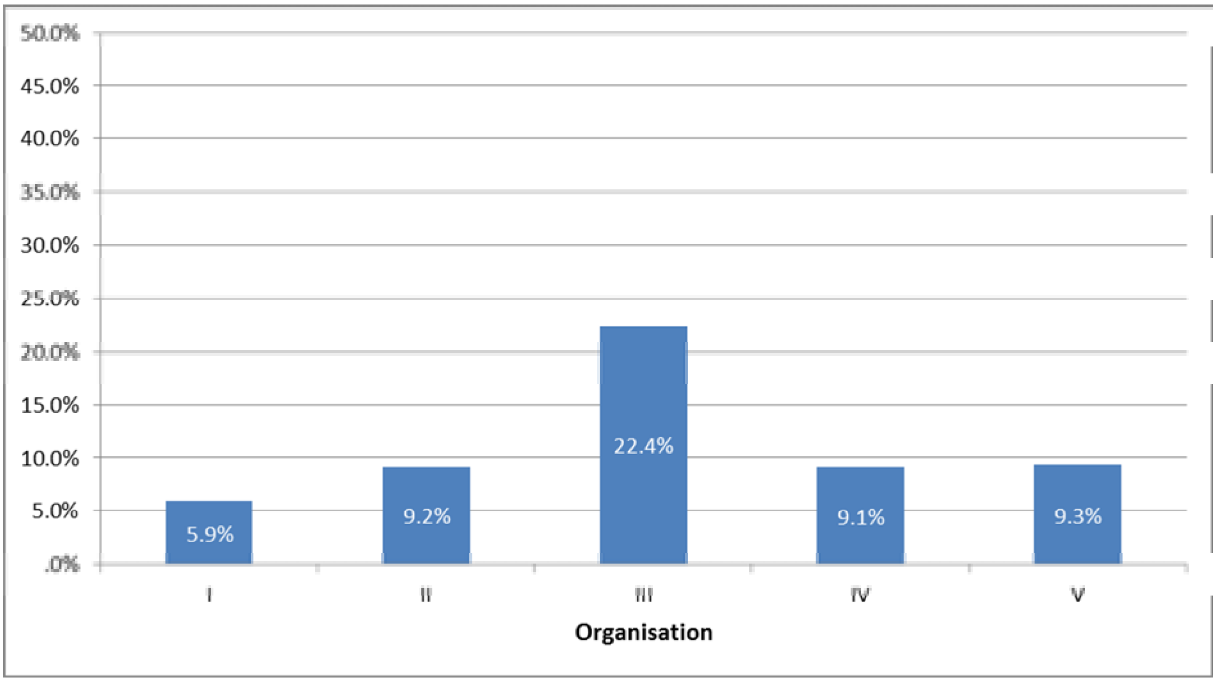


Figure 7 Percentage of occupants using a personal fan per organization

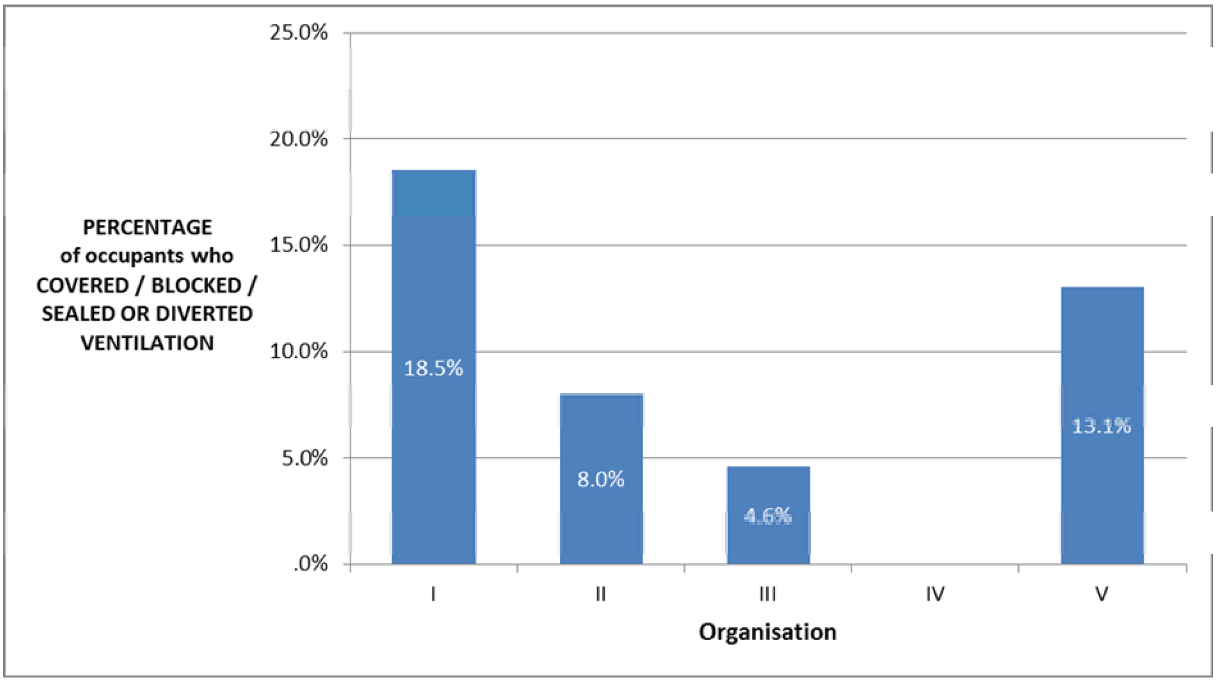


Figure 8: Percentage of occupants who manipulated ventilation ducts per organization

Discussion

The results show that employees control their comfort at work by bringing private electric devices and other equipment. These objects are not equally relevant for energy-consumption. However, coffee machines and fans may consume considerable amounts of energy.

A second indicator of energy-relevant behavior is the percentage of occupants who have carried out manipulations of the building or building technology in their work environment. The results show that more than 10 per cent tried to control their comfort by altering ventilation ducts. Additionally, 7 and 8 per cent blocked or opened windows or doors, respectively. Thus, a considerable number of employees thwart building-related energy or sustainability concepts.

With the multiple motivations approach to energy-consumption behavior at the workplace different reasons for energy inefficient behavior were assessed in their perceived importance by the employees. The results show that pro-environmental attitudes, self-efficacy for energy-saving behavior, and goal conflicts between energy-conservation and other domains are less important reasons than conflicting habits, lack of information, and lack of incentives. Thus, employees generally seem to care for environmental issues but are not aware of the possibilities to align their behavior with their attitudes.

Analyses of user knowledge confirm this finding. Survey participants most frequently mention switching off devices or shutting down computers as amongst the most effective actions office users could take in order to reduce energy consumption. These actions are obvious in the sense that they are associated with a direct feedback for the user. While these actions certainly contribute to energy-saving they may not be the most efficient measures for sustainable usage of office buildings (e.g. reducing heating / cooling will have a bigger impact). Because more and more electrical devices have power-saving functions, the effect of these actions may decline in the future. Thus, mechanisms of providing feedback to the users with regard to actions that do not have directly perceivable consequences will become more important for energy-saving behavior.

At least four limitations of the study must be mentioned: first, the operationalization of energy-relevant behavior is incomplete. While bringing own devices and manipulating the own work environment may be considered as a good indicator, other forms of behavior relevant for office building sustainability should be considered in further studies, e.g. use of electric installations, transport and travelling, or heating and cooling (where under control of employees). Second, the use of an ad hoc sample limits generalizability of the results. Differences between office buildings indicate that considerable variability can be found. Furthermore, the characteristics of the buildings, organizations, and facilities management practices and policies should be taken into account. Third, intercorrelations between the reasons for energy-inefficient occupant behavior are not considered in this article. Further research should aim at identifying causal relationships between behavior and attitudes, habits, self-efficacy, information, incentives, and goal conflicts by using longitudinal research designs. In order to identify such relationships, intercorrelations between the factors must be taken into account. Fourth, self-reported behavior measures may not be very reliable and information from user surveys may be biased due to social desirability [13]. Therefore surveying users should be complemented with more objective measures such as walkthroughs, sensor-based measures, or measures of energy consumption.

The results have important implications both, for theory and practice. From a theoretical point of view the multiple motivations approach proved fruitful. The results indicate that information, incentives, and conflicting habits are more important reasons for energy-inefficient behavior than attitudes, self-efficacy, or goal conflicts. Furthermore, there are significant differences between buildings and organizations indicating that building characteristics and organizational policies and practices may strongly influence employees' behavior in the context of sustainability of office buildings. Therefore interventions to change and improve users' behavior should be tailored to the specific situation. A goal-setting and feedback-intervention approach promises to be more effective than more general media-based persuasion strategies [see also 14, 15]. Furthermore, FM policies regarding personal devices and equipment as well as building-related manipulations should be formulated and communicated. Finally, information for users must be provided in order to enable them to understand the way the office building works and which actions are effective in relation to sustainability goals. Information and timely feedback on occupants' interventions have been shown to be a critical factor for their understanding of the way the office building works [10].

However, further research regarding such interventions is needed. Especially the interplay between individual motives, building characteristics, and organizational guidelines deserves more attention. Further studies comparing buildings and organizations are needed for a deeper understanding of sustainable office buildings in use.

Acknowledgements

This work was partially sponsored by the Commission for Technology and Innovation (Swiss Federal Office for Professional Education and Technology) through funding of the project „Quality of sustainable buildings – effects of sustainable office buildings on user comfort, well-being, and work performance“ (13115.1 PFES-ES).

The authors would like to acknowledge that they are solely responsible for this document and that it does not represent the opinion of the Commission or any of the project partners, and that the Commission or project partners are not responsible for any use that might be made of data appearing therein.

The authors gratefully acknowledge the comments and suggestions of one anonymous reviewer.

References

[1] Lutzenhiser, L., Social and behavioral aspects of energy use. Annual Review of Energy and the Environment, 1993. 18: p. 247-289.

[2] Lo, S.H., G.-J. Peters, and G. Kok, Energy-related behaviors in office buildings: A qualitative study on individual and organisational determinants. Applied Psychology: An international review, 2011. online first.

[3] Junnila, S., The environmental significance of facilities in service sector companies. Facilities, 2004. 22(7/8): p. 190-198.

[4] Newsham, G.R., S. Mancini, and B.J. Birt, Do LEED-certified buildings save energy? Yes, but. . . Energy and Buildings, 2009. 41: p. 897-905.

[5] Junnila, S., The potential effect of end-users on energy conservation in office buildings. Facilities, 2007. 25(7/8): p. 329-339.

[6] Steg, L. and C. Vlek, Encouraging pro-environmental behavior: an integrative review and research agenda. Journal of Environmental Psychology, 2009. 29: p. 309-317.

[7] Ajzen, I., The theory of planned behavior. Organizational behavior and human decision processes, 1991. 50: p. 179-211.

[8] Kaiser, F.G. and H. Gutscher, The proposition of a general version of the Theory of Planned Behavior: Predicting ecological behavior. Journal of Applied Social Psychology, 2003. 33(3): p. 586-603.

[9] Lindenberg, S. and L. Steg, Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social Issues, 2007. 63(1): p. 117-137.

[10] Brown, Z. and R.J. Cole, Influence of occupants' knowledge on comfort expectations and behavior. Building Research & Information, 2009. 37(3): p. 227-245.

[11] Wilson, C. and H. Dowlatabadi, Models of decision making and residential energy use. Annual Review of Environment and Resources, 2007. 32: p. 169-203.

[12] Aiken, L. R. (1996). Rating scales and checklists. Evaluating behavior, personality, and attitudes. New York: John Wiley & Sons.

[13] Spector, P.E., Method variance in organizational research. Truth or urban legend? Organizational Research Methods, 2006. 9(2): p. 221-232.

[14] Abrahamse, W., et al., A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology, 2005. 25: p. 273-291.

[15] Abrahamse, W., et al., The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. Journal of Environmental Psychology, 2007. 27: p. 265-276.

Energy-efficiency investments and energy management: An interpretative perspective

Catherine Cooremans

Eco'Diagnostic, Geneva

Abstract

"Strategicity" (which we define as an investment's contribution to a firm's competitive advantage) is the main driver of capital investment decision-making, and is even more important than profitability. This finding is based on an extensive review of different streams of literature, and is confirmed by our own research.

Yet investments are not (only) strategic for objective reasons. They are interpreted as such. Strategic issue diagnosis assesses new issues and categorizes some of them as decision events, more or less strategic. Individual and organizational filters influence issue diagnosis. At the individual level, information is distorted by the use of heuristics, by cognitive biases, and by managers' personal knowledge systems. At the organizational level, three major organizational filters influence how decision-makers interpret issues: strategy, culture and structure. Structure includes management systems and routines, which frame and control actors' behavior. The meaning attributed to the same event, and the type of reaction to this event, will therefore be different from one organization to another.

Based on this theoretical framework, our research, conducted by thirty-five major electricity consumers (more than 1 GWh/year) in various commercial and industrial sectors, has investigated the link between energy-efficiency investments and energy management, an element of organizational energy-efficiency culture and of the general management system. Results highlight a relation between the level of energy management and the [perceived] strategicity of energy-efficiency investments. Yet, results show huge behavior diversity between firms, even those with similar characteristics and activity.

These findings help better understand how and why companies make energy-efficiency investment decisions.

Introduction

Financial logic is not the first driver of investment decision-making. Investment decision-making is the result of a decision-making process. This process is influenced by organizational and external contexts, the actors involved, and characteristics of the investment to be made. Among investment characteristics, strategic character is a key factor influencing decision-making (Cooremans, 2011 and forthcoming).

Yet strategic character is not given, it is interpreted. Investments projects are interpreted as strategic, by actors[1] and by organizations, as are interpreted all data and decision events. At the beginning of the decision-making process, issue diagnosis assesses and categorizes new data and events which are "infused with meaning" (Dutton and Jackson, 1987) at the individual and organizational levels.

During the issue diagnosis process, information is distorted or interpreted, both at the individual and at the organizational levels. At the individual level, information is distorted by the use of heuristics—rules of thumb, shortcuts, and routines which decision-makers use to simplify complex problems—and by cognitive biases, these "hidden decision traps" (Hammond, Keeney, & Raiffa, 2001) common to all individuals. Moreover managers' personal pre-existing knowledge systems act as filters[2] of

[1] In the field of organization behavior, "actors" mean individuals and groups.
[2] "Executives' experiences, values, and personalities affect their field of vision (the directions they look and listen), selective perception (what they actually see and hear), and interpretation (how they attach meaning to what they see and hear)" (Hambrick, 2007: 337).

organizational events. Filters also operate at the organizational level, since the organizational context influences how decision-makers understand and interpret issues. The meaning attributed to the same event, and the type of reaction to this event is therefore different from one organization to another. As a result, the same investment project may be perceived as more or less strategic by different decision-makers and organizations. There are interactions and mutual influences between individual and organizational levels: organizational context controls managers, but managers influence organizational context. Organizational context comprises structure, routines, strategy and organization culture.

Organizational culture is one of the most powerful filters, or interpretative schemes, influencing organizations' behavior. One good definition of culture according to the interpretative perspective on organizations is proposed by Cossette (2004:121):

> "Culture is an organizational scheme, mainly composed of values which are more or less shared, more or less consciously, by organization members. It is a normative system of ideas, ultimately shaped by the actors involved themselves; thus culture is created, maintained and transformed by individuals who, themselves, have schemes, some of those being of a normative nature, i.e. composed of these individuals' personal values. This organizational scheme of culture is in close relationship with other organizational schemes, even if the influence of one scheme on another goes through individuals… The concept of culture almost always refers to values, defined as what is desirable in a given spatio-temporal context."[3]

In the field of energy efficiency, the influence of organizational culture on energy-efficiency investment decisions and/or on the level of energy efficiency in organizations was noticed by several researchers, but none of them proposed a precise definition of the concept. For instance, Sorrel *et al.* (2000, p. xvii) briefly indicate that culture includes "values, standards and routines," and that "organizational culture makes reference to environmental values incorporated into the routines and the customs of the organization" (idem, p. 13). As noted by Stern and Aronson: "...organizations have energy-related values that affect their actions" (Stern et Aronson, 1984, p. 184). Three organizational values are mentioned by research as positively influencing energy efficiency: an orientation towards technical innovation (Kulakowski, 1999; Hennicke et al., 1998, p. 38), employees' welfare[4] (Kulakowski, 1999), and environmental commitment (Christoffersen et al., 2006; Hennicke et al., 1998; Sorrell et al., 2000). However, regarding the latter value, Sorrell et al. (2000:178) indicate that: "generally, environmental commitments do not seem to be a significant variable in explaining the energy efficiency performance of organizations and promotion of environmental management systems does not seem a priority measure for improving energy efficiency."

The concept of "energy efficiency culture" is little used. One definition is given by the electricity producer Hydro Québec: "energy-efficiency culture affects all aspects of the organizational life. Carried by a global vision, it goes beyond a better energy performance of equipments or processes. It encompasses a stream of actions which, encouraged by all the members of a company, quickly become work habits."[5] This definition emphasizes the human dimension of energy use as opposed to

---

[3] Freely translated by me from: " La culture est un schème de niveau organisationnel constitué essentiellement de valeurs qui sont partagées dans une mesure plus ou moins grande et de façon plus ou moins consciente par les membres d'une organisation. Elle est un système d'idées à caractère normatif, façonné ultimement par les acteurs concernés; la culture est donc créée, maintenue et transformée par des individus possédant eux-mêmes des schèmes, certains de nature normative, c'est-à-dire formés par les valeurs personnelles des individus. Ce schème organisationnel qu'est la culture est en relation étroite avec d'autres schèmes organisationnels, même si l'influence de l'un sur l'autre passe forcément par les individus … La notion de culture renvoie donc presque toujours à des valeurs, c'est-à-dire à ce qui est jugé comme souhaitable ou désirable dans un contexte spatio-temporel donné."

[4] "…a corporate culture that values innovation, "technology" in general, and has consistently supported improvements to the working environment" (Kulakowski, 1999, p. 11).

[5] Hydro Québec, Mieux consommer pour mieux performer, Sept. 2008, http://www.hydroquebec.com/grandesentreprises/ee/initiatives_batiments/pdf/programme_complet.pdf.Freely translated by me from: "Une culture de l'efficacité énergétique touche tous les aspects de la

its technical dimension and the fact that energy efficiency culture affects all aspects of how an organization functions. However it does not give indications of the values related to an organizational culture of energy efficiency. Another mention of energy efficiency culture is made by Hennicke, et al. (1998:118). These researchers do not define the concept but simply indicate that "energy efficiency culture in SME… starts with simple measures and continues with rather complex activities such as eco-management" (Hennicke, et al., 1998, p. 118). According to this description, energy-efficiency culture may be more or less strong.

This brief review illustrates the need for a better conceptualization of organizational energy-efficiency culture and of the values related to it, as well as the need for a better understanding of how cultural factors play a role in energy-efficiency decision-making.

Within this context, our research aimed at highlighting a link between the importance of energy-efficiency in corporate culture and the perception of the strategic character of energy-efficiency investments.

The goal of this paper is to describe our research findings. To address this, the paper is organized into three parts. The first part describes our theoretical framework, the second part describes our research methodology and results, and the third part discusses the results. The conclusion briefly indicates the implications of our findings in the field of energy-efficiency.

Theoretical framework

Organizational culture

Edgar Schein's theory of organizational culture (1985) provides a useful framework to better understand how culture plays a role in organizations' behavior and decision-making.

Schein, one of the most important theoreticians of organizational culture, distinguishes between three major levels of culture—or levels of cultural analysis—defined as the "degree to which the cultural phenomenon is visible to the observer" (Schein, 2004:25; first published in 1985). These levels range from the less to the most visible or tangible. At the deepest, least visible level, are the basic assumptions, deeply embedded and subconscious, which Schein defines as "the essence of culture." Basic assumptions comprise beliefs, perceptions, thoughts and feelings. They are "taken for granted by group members and are treated as nonnegotiable." At the most visible and tangible level, are the artifacts, the "overt manifestations that one can see and feel." In between these two levels, and underlain by the basic assumptions, are the "espoused beliefs, values, norms, and rules of behavior" (idem). These in turn influence attitude (people's ideas, convictions or tastes) and behavior (what people are doing)." (Schneider & Barsoux 2003:22).

Schein's levels of culture are represented in figure 1 on the next page.

---

vie organisationnelle. Portée par une vision globale, elle va au-delà d'une meilleure performance énergétique des équipements ou des processus. Elle comporte une kyrielle d'actions qui, encouragées auprès de tous les membres d'une entreprise, deviennent rapidement des habitudes de travail."

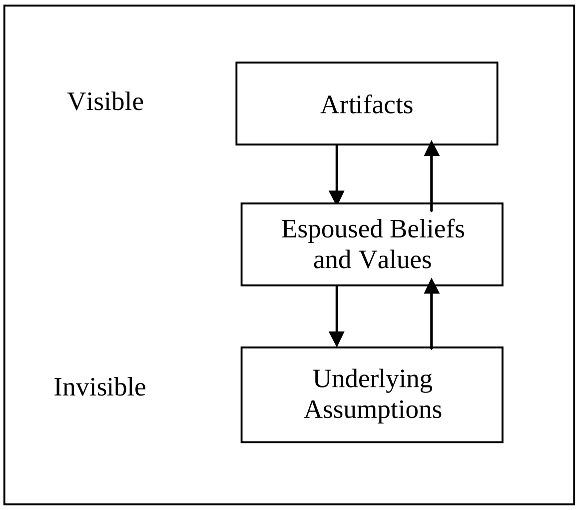


Figure 1 – Levels of culture. Adapted from Schein (2004:26) and Kluckholn et Strodtbeck (1961).

The most important point regarding artifacts, as emphasized by Schein, is that they are both easy to observe and difficult to decipher because artifacts are "manifestations of culture… but not the essence of what we mean by culture" (2004:14). Artifacts include "all the phenomena that one can sees, hears, and feels when one encounters a new group with an unfamiliar culture, such as the architecture of its physical environment, its language, its technology and products, its artistic creations; its style, as embodied in clothing, manners of address, emotional displays, and myths and stories told about the organization; its published lists of values; its observable rituals and ceremonies; and so on (idem, p. 26). Artifacts also include structural elements, such as charters, as well as organization processes, procedures, routines, and reward and control systems.

Energy management: an artifact of energy-efficiency culture

Control systems of an organization can be considered as artifacts of its culture (Johnson, 1989; Schein, 2004). Control systems include management systems. Energy management can therefore be regarded as an artifact of organizational culture, as a manifestation of a company's energy-efficiency culture.

If energy management is a manifestation of energy-efficiency culture, then energy management should act as a filter, positively influencing the perception of energy-efficiency investment strategicity, through creating a more favorable organizational context to these investments.

Therefore we can emit the following hypothesis:

> **The level of energy management influences companies' perception of energy-efficiency investment strategicity.**

In other words, the higher the energy-efficiency management, the higher the perceived strategicity of these investments.

This hypothesis is also justified by the fact that several works or public programs have shown how energy management positively influences organizations' energy consumption (Beard, 2009 ; Seo, 2009 ; McKane, et al., 2007 ; Tunnessen, 2004). In this regard, we don't know if the energy consumption reduction observed in relation with a high level of energy management is due to a better use of existing equipment (i.e. optimization best practices), and/or to a positive influence on energy-efficiency investment decision-making. This point is not discussed in the literature.

To assess the validity of our hypothesis, we must first assess the level of energy management in organizations and, secondly, compare energy management level to the perceived strategicity of energy-efficiency investments.

Based on the theoretical framework described above, our empirical study was conducted in Geneva, Switzerland, from 2006 to 2007.

Empirical research

Methodology

The research was made in collaboration with the University of Geneva Business School (HEC) and the Geneva Energy Office (ScanE), and based on interviews and questionnaires submitted, from June 2006 to June 2007, to major electricity consumers of the Geneva canton (sites consuming more than 1GWh of electricity per year), participating in a peak demand-side management program. Thirty-five companies supervising sixty-one buildings or industrial sites participated in the survey, nineteen of which are active in the secondary sector (metalworking, clock- and watch-making, chemical and pharmaceutical industries) and the rest of which are active in the tertiary sector (chain stores, parking lots, shopping malls, conference/exhibition centers).

Energy Management. To assess the level of energy management in the companies of our sample, we formulated eighteen questions (based on NL Agency[6] "Energy Management Checklist"[7] and on Mc Kane, et al., 2004, framework), which compose a simplified audit of energy management in organizations. The questions concern the following elements: diagnosis of current consumption, energy policy, presence of an energy manager in the organization, key performance indicators, measurable objectives and monitoring of energy consumption reduction, resources allocated to achieve energy saving measures, evaluation and revision of energy saving goals, and staff training and rewards. Fourteen questions out of eighteen were worth one point and four questions were worth two points. Thus the maximum score attainable was twenty-two points. Our energy management questionnaire is represented in annex 3.

The higher the score obtained by the organization questioned, the higher the level of its energy management. According to our theoretical framework (see the section on organizational culture on page 3), since energy management is an artifact, or a manifestation, of energy-efficiency culture, we can admit that the higher the energy management of an organization, the higher its energy-efficiency culture.

Our energy management audit questionnaire was filled in on the occasion of a semi-directive interview with the manager responsible for energy issues (usually the facility or technical manager) in the thirty-five companies of our sample.

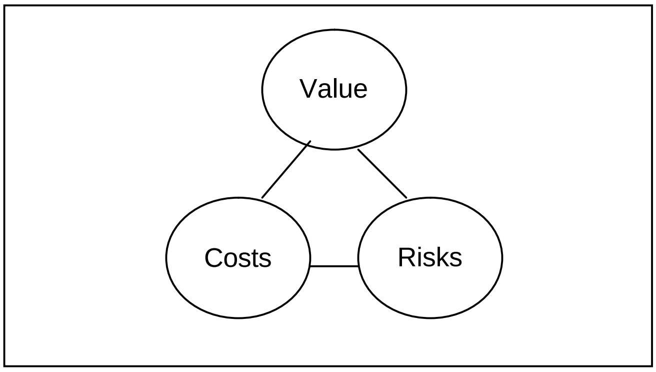
Energy management and strategicity. To analyze the influence of organizational energy management on the perception of energy-efficiency investment strategicity, we have to analyze the relationship between the level of energy management (a manifestation of energy-efficiency culture) and the strategic character of energy-efficiency investments (or, more exactly, energy managers' perception of strategic character). In order to do so, we have to examine the strength of the relationship between two groups of variables: on the one hand, the eighteen variables (independent variables) which define a company's energy management level and, on the other hand, the three (dependent) variables which make up the strategic character of energy-efficiency investments.

According to our definition, the more an investment contributes to create or to strengthen a company's competitive advantage, the more strategic it is (or, in other words, the higher its strategicity). Competitive advantage is a three-dimensional concept, composed of three interrelated constituents: costs, value, and risks. Figure 2 on the next page very simply represents these three dimensions of competitive advantage.

---

[6]Deutsch energy agency, previously called "SenterNovem". http://www.senternovem.nl/english/
[7] http://www.senternovem.nl/mmfiles/3MJAF04.15%20-%20Energy%20Management%20Checklist%20-%20June%202004_tcm24-122945.pdf

Figure 2 – The three dimensions of competitive advantage[8]



Based on the measurement tool defined[9], energy managers were asked to rate—from 1 to 5—the contribution of energy-efficiency investments to decreasing risks, decreasing costs and increasing product value in their company. Therefore, on a scale ranging from 0 to 15, the highest possible score for energy-efficiency investments strategicity was 15 points. The average score for energy managers' answers was 9,1 out of 15, which means that these investments are perceived as non- to moderately strategic by our respondents. Again this average score hides a wide variety in the answers.

Results

Energy management. With regard to energy management, the most striking results are the following: energy management in the companies of our sample is low, with an average score of 8.9 points out of a maximum achievable of 22. The average score is slightly higher (9.6 out of 22) in the 15 tertiary sector companies having answered than in the 18 secondary sector companies (8.3 out of 22). However average results hide a huge variety of situations between companies within the same industry. Out of the thirty-five companies questioned, only two had a manager exclusively dedicated to energy.

Strategicity of energy-efficiency investments. On average, energy-efficiency investments are considered "not strategic" to "moderately strategic" for their company by the respondents managers. Again, a variety of interpretations is observed. Generally speaking, investments in energy efficiency obtain a higher score in the three dimensions of competitive advantage ("risks," "costs," and "value") with managers of the tertiary sector than with those of the secondary sector.

Table 3 on the next page shows the results for the two dimensions combined for each company of our sample. The table shows that, at first sight the relationship between the two dimensions follows very diverse scenarios: sometimes strategicity is quite high while energy management is quite low, sometimes it is the opposite. Sometimes both strategicity and management levels are high, sometimes both levels are low. A statistical analysis of energy managers' answers confirm these initial conclusions: simple correlation between both groups of variables—energy management level and strategicity—is very low at 0,14. However, we notice six "extreme cases" made up, on the one hand, of three companies having a very high level of energy management and a very low perception of energy-efficiency investment strategicity and, on the other hand, of three companies having, on the contrary, a rather high perception of investment strategic character and almost non-existent energy management. If we remove these six extreme cases, we obtain a simple correlation which is higher, at 0,62.

[8] Cooremans, 2012, forthcoming, p. 12.
[9] Methodology to measure strategicity is described in details in Cooremans (forthcoming). For more details regarding strategicity measurement please see Annexes 1 and 2. Detailed results are presented in Annex 3.

Table 3 – Energy management and strategicity levels

Company no.	Business industry	Strategicity score /15	Energy mgt score /22
1	Chain store	13	17.5
2	Chain store	10	8.0
3	Chain store	10	20.0
4	Chain store	7	19.0
5	Chain store	7	7.0
6	Furniture chain store	10	--
7	Space renting /event mgt	11	7.5
8	Space renting / shopping mall	8	6.0
9	Parking lot	13	8.5
10	Bank	12	6.0
11	Finance news	10	3.0
12	Hotel	10	20.0
13	Hotel	10	8.0
14	Hotel	8	0.5
15	Services b2b	10	6.5
16	Services b2b	9	6.0
16	**Tertiary sector 16 entities - 36 sites**	**158 9.9 sur 15**	**143.5 9.6 /22**
17	Chemical	8	7
18	Chemical	4	19.5
19	Chemical	13	13
20	Food production	7	8
21	Pharmaceutical	--	--
22	Metals	13	19
23	Metals	11.5	14
24	Metals	5	17.5
25	Metals	8	8
26	Metals	10	2
27	Metals	8	4
28	Metals	10	0
29	Metals	7	2
30	Metals	8.5	9
31	Electronics	7	8.5
32	Watchmaker	5	0
33	Watchmaker	9	9.5
34	Watchmaker	8	0
35	Food transformation	9	8
19	**Secondary Sector 19 entities - 24 sites**	**151 8.4 /15**	**149 8.3 /22**
35	**Total sample 35 entities - 60 sites**	**309 9.1 /15**	**292.5 8.9 /22**

Discussion

Regarding the cultural dimension of energy-efficiency investments, three important conclusions can be deduced from the findings: 1) the link between the level of energy management of a company and its perception of the strategic character of energy-efficiency investments in energy efficiency is not clearly established and our hypothesis is not validated; 2) cultural influences play, nevertheless, an indisputably important role on the perceptions of energy managers regarding these investments; 3) organizational culture plays a more important role than business industry culture. Let us discuss these three conclusions in detail. Another important finding, although not discussed in this paper, is the low level of energy management in the majority of the companies in our sample.

The first important conclusion is that our findings do not confirm our hypothesis. Indeed, research results do not highlight a strong link between the level of energy management—which is considered in the research as a manifestation (artifact) of the level of energy-efficiency culture—and the strategic character of energy-efficiency investments. However the cloud of points in the graph below shows a relation between the perception of the energy-efficiency investment strategic character (in abscissa) and the level of energy management (in ordinate) for a majority of companies in the sample.

Figure 3 below illustrates the correlation between the level of energy management and the level of strategicity of energy-efficiency investments. It shows a trend toward a correlation between these two values for the majority of the companies of the sample, to the exception of the six extreme cases. If we remove these six extreme cases from the analysis, simple correlation jumps from 0,14 to 0,6264, a result which shows a relation between both groups of variables.

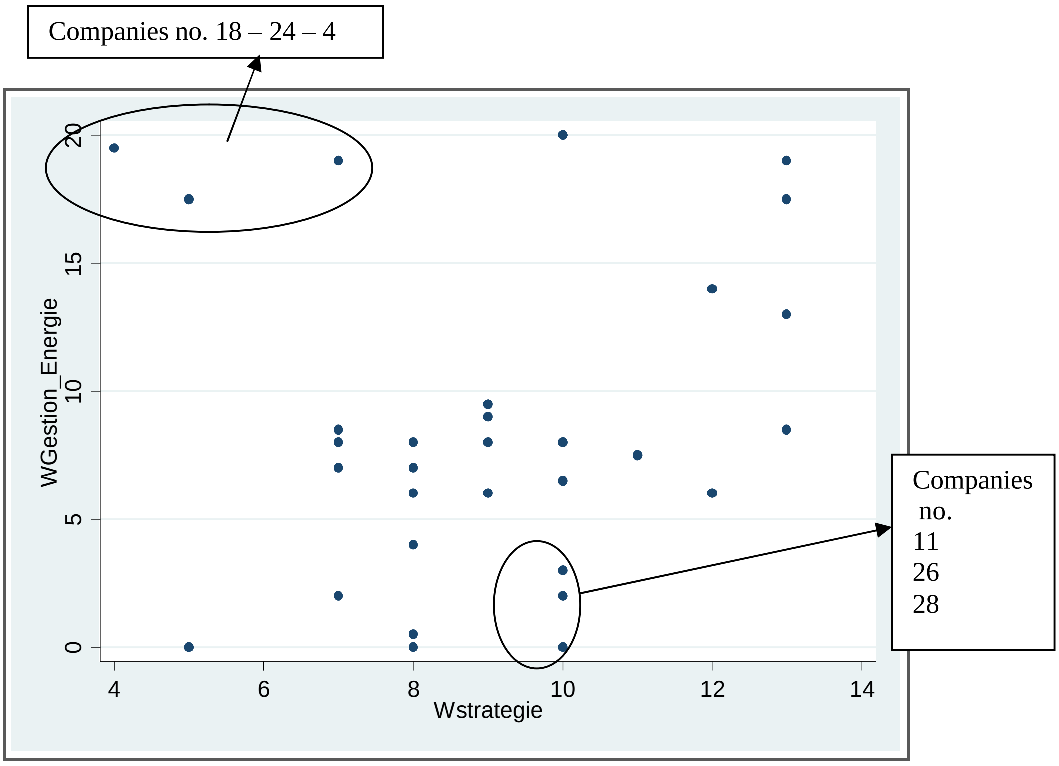


Figure 3 – Correlation between energy-efficiency investment perceived Strategicity and energy management level in 33 companies of the sample.

The correlation between the two groups of variables must be analyzed by examining the extreme cases more closely. As already mentioned, these fall into two groups: one group includes three companies, which see energy efficiency investments as strategically low and yet have a very high level of energy management (greater than or equal to 17.5 out of 22) . The second group encompasses three companies, which perceive investments as moderately strategic, and yet have a level of almost nonexistent energy management (less than or equal to 3 out of 22). Both groups are represented in table 2 below. They are also surrounded in the graph above. Companies whose points are circled in the graph are discussed in further detail in the following pages.

Table 2 – "Extreme cases" energy management - strategicity

Company. No.	Business industry	Strategicity Max score = 15	Risks	Costs	Value	Energy management Max score = 22
18	Chemical	4	1	2	1	19.5
24	Metals	5	1	3	1	17.5
4	Chain store	7	1	4	2	19.0
28	Chemical	10	2	5	3	0.0
26	Metals	10	4	4	2	2.0
11	Finance news	10	1	5	4	3.0

The first group—low strategicity and high energy management—include companies N° 18 (fine chemicals), N° 24 (steel) and N° 4 (retail).

The most extreme case is that of company N° 18 (Swiss, fine chemicals, 1'895 employees in 2006, of which 780 in Geneva). The manager in charge of energy (head of infrastructure, in the business for 22 years, who reports to the Technical Director) considers as very low (score 4 out of 15) the strategic character of energy-efficiency investments, while the level of energy management is very high (19.5 out of 22). But the energy-efficiency culture of the company has developed over many years (three energy audits were conducted between 1996 and 2006), it is deeply rooted in the company, and it corresponds, firstly, to a tradition of monitoring of technological development and, secondly, to a high sense of corporate social responsibility. The result of this configuration is that, although energy efficiency is not perceived as a strategic issue by the company, many energy savings measures have been implemented.

In the second case, firm N° 24 (second point from the left at the top of the chart, a Swiss company, metal accessories, energy costs 0.8% of sales, 1.2% before the appointment of an energy manager, 250 employees, of which 200 in Geneva), the energy manager is the company's technical and industrial manager, responsible for quality, safety and environment, directly reporting to senior management. For him, trained as a metallurgical engineer, fighting against waste of resources is "a matter of honor." In the company since 2001, he has developed a real passion to bringing energy management to a high level (17.5 out of 22). But his achievements are not representative of the strategic dimension of energy (5 out of 15) for the company's owner, an investment fund based in the German side of Switzerland, which bought the company in 2005.

The last case, more difficult to interpret, is company N° 4, a huge Swiss retail chain (3.800 employees in Geneva), third point from the left in the top of the table. Here, we argue that the low strategicity of energy-efficiency investments does not have to be interpreted literally. The energy manager mentions in the interview (June 9, 2006) that "technical services are serving the sales department, which is the client and pays." There are often disagreements between the two services that pursue different objectives: the sales department wants to sell, the technical department wants to improve customer comfort and to reduce energy consumption. Employees of the technical department are therefore considered as a source of trouble by employees of the sales department. This situation could explain why the energy manager perceives the contribution of energy-efficiency investments as small compared to the value of the company's offer. A second reason suggests that energy-efficiency investments' strategic value is higher for the company than is perceived by the Geneva energy manager: it is the fact that, as stated in the sustainability report, energy is one of the "key action areas where the company marks its difference." In this search for strategic differentiation, the first "Minergie store"[10] was opened in Geneva in 2009 and, generally, the company has defined a very active and ambitious policy for its facilities and infrastructure.

The second group of extreme cases—i.e. the group with (moderately) high strategicity but with almost nonexistent energy management—includes companies N° 28 (steel), N° 26 (steel) and N° 11 (financial news). Let us also analyze these cases.

The first case is company N° 28, a small business (45 people) specialized in the manufacturing of highly technical screws, the world leader for this product which is used in space aviation, turnover grows annually by 12%, and sales have quadrupled in ten years. The company has only recently become concerned with energy efficiency, but with rather high motivation, according to the production manager (also in charge of energy; interview of 23 March 2007) concerning four strategic goals: "cost reduction; pollution reduction, a better corporate image and increased productivity thanks to a more comfortable and stable building."[11] Manufacturing entails heat production which is not recovered and spreads through the huge spaces of the badly insulated building;[12] this causes discomfort for staff and high energy consumption due to the air conditioning necessary to cool down the building. A fifth strategic motivation is to respond to customer requests because the company "is moving increasingly towards high technology sectors that attach more importance to these issues." In this case perception of energy-efficiency investment strategicity clearly precedes implementation of energy management, which is completely nonexistent in the company.

In the second case of the second group, is company N° 26, also a small business (25 people), niche market, activity of surface treatment of metal pieces. Electricity costs amounted to 5% of 2006 turnover, of which 75-80% for production. Energy costs reduction is a strategic necessity for the company confronted to a low-cost competition (i.e. production costs in Germany for this type of activity are 40% lower than those in Switzerland). Despite this strategic concern, there is a "lack of time for energy efficiency" and "energy for us, it's a commodity" as stated by the company's owner (interviews of February 21 and March 8, 2007). This perception of energy as a commodity (as well as the very small size of the business) probably explains why, although energy-efficiency investment strategicity looks high, energy management is virtually nonexistent in the company.

The last case of (relatively) high strategicity and very low energy management is company N° 11, specialized in financial information to businesses and individuals, with 15,000 employees, of which 550 are located in Geneva. The company headquarters are based in London and its CEO is a jurist by training. The person in charge of energy in Geneva is an electronics engineer by training, with no management skills. Decisions regarding energy-efficiency investments are made in London. Sustainable use of resources is described as a strategic goal for this company, but the energy manager considers as unimportant the contribution of energy-efficiency investments to risks reduction. And yet, as he himself pointed out during the interview (October 6, 2006), electricity use is a problem in the company's building (which dates from 1997). As stated by the energy manager: "electricity is a bane, because of the many failures." The building heating and air conditioning do not work well, while the 8,000 data center servers have a vital need for a quality power supply and for a stable temperature. Greater efficiency and better management would increase energy security and reliability of facilities, which are at the core of the company's business. A lack of real understanding of energy-efficiency investments, as well as of the procedures and benefits of a sound energy management probably explain why, in this context where energy efficiency is in all respects a strategic imperative, energy management is almost nonexistent.

These examples show that the level of energy management is not always strictly related to the strategic nature of investments in energy efficiency; but this does not mean that energy management is not a relevant indicator of perceived strategicity of these investments in many cases.

These examples also show that the relationship between the strategic nature of the investment and the level of energy management actually works both ways: sometimes it is energy efficiency strategic character which influences the level of energy management. In this case, the top management of the

[10] A Swiss label for very low energy consumption buildings.
[11] Because the better the working conditions and "the more stable the temperature, the greater the productivity gains."
[12] The building was built in 1982.

company, convinced of the importance of energy, sets up a high level of energy management (sometimes with the help of external actors).[13] In other, contrasting, cases, energy management comes first and contributes to increase energy-efficiency investments strategicity by creating a favorable organizational context to these investments.

These descriptions show that a better understanding of companies, making the link with their core business, their history and their culture, is essential to successfully promote energy efficiency. This points out to the need for a customized approach to businesses. Thanks to sound technical assistance (both in terms of energy efficiency projects and in terms of management procedures), the integration of energy issues in companies' strategic concerns and control systems can be much improved, leading to a more efficient use of energy.

Indeed, energy management improves the organizational context of energy-efficiency investment decision-making process. It provides a framework for analysis and control, which allows the investment project to be positively categorized in the diagnostic phase of decision-making as a project interesting enough to be adopted.

The second conclusion of our research is that, even if our hypothesis is not confirmed, the influence of the cultural dimension is obvious in energy and finance managers' responses (see annex 2 for detailed results). Professional and functional cultures influence managers' perceptions. Indeed, energy managers regard the strategic advantages "cost reduction" and "increasing value" of energy-efficiency investments as most important, whereas for finance managers, risk reduction is more important.[14] Finance managers' answers also show that they consider their company's infrastructure as more efficient and energy costs as less important[15] than do their colleagues in charge of energy.

Finance managers are also more uncertain about the choice and quality of energy-efficient technologies in which their company could invest. For all these reasons, financial managers may not be favorably disposed towards energy-efficiency investment projects, a situation which heavily penalizes this investment category in so far as finance managers are generally more powerful than energy managers.

The third important conclusion of our research is that the diversity of behaviors between companies, even within the same industry, rules out a priority influence of business sectors logic on investment decisions. This generalization must be understood with some exceptions: for example, as mentioned, low costs are a strategic imperative for certain sectors. Overall, however, each company has its own logic of choice and action. In this regard, corporate culture plays an important role as filter in weighting events and solutions and, ultimately in making decisions. Yet, in the field of energy efficiency, this role has been very little studied.

We have not tried to systematically identify, in the research, values attached to energy-efficiency culture—or to energy conservation. However references to values were spontaneously made by interviewees. They can be tentatively grouped into six categories:

- Efficient resources management and cost savings;
- Integration with Quality and Safety;
- Technological innovation ("pioneer spirit");
- Environmental protection and corporate social responsibility;
- Improvement of working conditions;
- Autonomy (a point related to security of energy supply).

[13] This logic is underlying PowerSmart, a demand-side management program of the Canadian electricity producer BC Hydro. PowerSmart first step is a two-hour interview with an applicant company top management to assess the level of energy strategicity and the one of energy management (Seo, 2009).
[14] See Annexes 1 and 2 for the detailed figures.
[15] Indeed, the fact that they consider energy costs as not important enough is the first barrier to energy-efficiency investments for finance managers of our sample.

Conclusion

Our hypothesis postulated that the level of energy management influences companies' perception of energy-efficiency investments' strategicity. In other words, the higher the level of energy management, the more strategic these investments would be considered by businesses.

As discussed above, this hypothesis is not validated by the research. However, our findings show that organizational culture and professional (or functional) cultures influence companies' and decision-makers' perceptions of the strategic character (or strategicity) of investments. Our findings also importantly show that organizational culture plays a much more important role than business industry culture. This contributes to explaining the diversity observed in companies' behavior regarding energy management and energy-efficiency investment decision-making. It also entails a customized approach to influence companies' decisions.

A secondary objective of the research was to highlight the influence of functional (sub)cultures on the perception of investments strategicity. Regarding energy efficiency investments, we can assume, for example, that the members of an organization performing technical functions (including the functions of production, infrastructure management, facility management) have a different perception of energy-efficiency investments than their colleagues in charge of finance, sales or marketing departments. To evaluate possible differences in perceptions, both managers in charge of energy and financial managers were asked several identical questions. This is an original approach, as this research is the first attempt to identify differences in perceptions by managers of different functions within companies. Indeed, with very few exceptions, research on investment decision-making does not mention the function of the respondents in companies.

The importance and the modalities of cultural influences on organizations' behavior have to be further investigated by future research. Yet the cultural dimension of energy-efficiency investments would have to be better taken into account by policy makers when framing energy-efficiency public programs.

References

[1] Beard, M. 2009. America's workplaces go green with energy star®. Presentation at BECC 2009, Behavior Energy and Climate Change Conference, Session 3C, Workplaces and Organization ,Washington nov. 2009. Information: http://www.stanford.edu/group/peec/cgi-bin/docs/events/2009/becc/presentations/3C%20Beard.pdf

[2] BESS Benchmarking and Energy Management Schemes in SMEs. 2007. Step by Step Guidance for the Implementation of Energy Management, Intelligent Energy Europe (IEE), EIE/04/246/S07.38678, Vienna.

[3] BSI The British Standards Institution. 2009. *Energy management in the UK, energy management research survey*. Milton Keynes.

[4] Christoffersen, L B., Larsen, A., & Togeby, M. 2006. *Empirical analysis of energy management in Danish industry*. Journal of Cleaner Production, 14: 516-526.

[5] Cooremans, C. (forthcoming). *Investment in Energy Efficiency: Do the Characteristics of Investments Matter?* Energy Efficiency.

[6] Cossette, P. 2004. *L'organisation Une perspective cognitiviste*. Laval: Les Presses de l'Université Laval

[7] Dutton, J., & Jackson, S. 1987. *Categorizing strategic issues: Links to organizational action.* Academy of Management Review. 12(1).

[8] Hambrick, D. C. 2007. *Upper Echelons Theory: an Update*. Academy of Management Review, 32(2): 334-343.

[9] Hammond, J. S, Keeney, R. L., & Raiffa, H. 2001 (6th ed).*The Hidden traps in decision making.* In Harvard Business Review on Decision Making, 143-167. Boston: Harvard Business School.

[10] Hennicke, P., Ramesohl S.& al. 1998. *Interdisciplinary analysis of successful implementation of energy efficiency in the industrial, commercial and service sector, Final report.* Research funded in part by the European Commission in the framework of the Non Nuclear Energy Programme JOULE III, Copenhagen, Karlsruhe, Kiel, Vienna, Wuppertal.

[11] Johnson, G. 1989. *Strategic change and the management process*. Oxford: Basil Blackwell.

[12] Kulakowski, S. 1999. *Large organizations' investments in energy-efficient building retrofits*, LBNL-40895, Energy Analysis Department, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley.

[13] McKane, A., Williams, R., Perry, W., & Tienan, L. 2007. *Setting the standard for industrial energy efficiency*. Proceedings of EEMODS'07, Energy Efficiency in Motor Driven Systems, Topic 9, paper 070.

[14] Schneider, S. C., & Barsoux J.-L. 2003. *Managing across cultures* (2nd ed.). London: Prentice Hall.

[15] Schein, E. H. 2004. Organizational culture and leadership. (3rd ed.). San Francisco: Jossey- Bass.

[16] SenterNovem. 2004. Energy management checklist, Utrecht. Information: www.Senternovem.nl

[17] Seo, P. 2009. *Whose job is it anyway? Energy managers make efficiency "business as usual"*. Presentation at BECC, Behavior Energy and Climate Change Conference, Session 3C, Workplaces and Organizations, Washington, 17 novembre 2009. Information: http://www.stanford.edu/group/peec/cgi-bin/docs/events/2009/becc/presentations/3C%20Seo.pdf

[18] Sorrell, S., Schleich, J., Scott, S., O'Malley, E., Trace, F., Boede, U., Ostertag, K., & Radgen, P. 2000. *Reducing barriers to energy efficiency in public and private organisations,* Final Report, SPRU, JOS3CT970022, Research funded in part by the European Commission in the framework of the Non Nuclear Energy Program JOULE II.

[19] Stern, P., & Aronson, E. (Eds).1984. *Energy use the human dimension*. Committee on Behavioral and Social Aspects of Energy Consumption and Production, National Research Council. New York: Freeman and Company.

[20] Tunnessen, W. 2004. *Closing the energy management gap*. Environmental Quality Management, 14(1): 49-57.

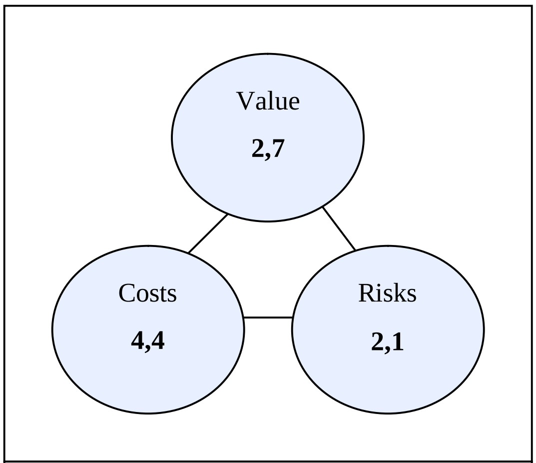
Annexes

Annex 1 - Measurement of strategicity

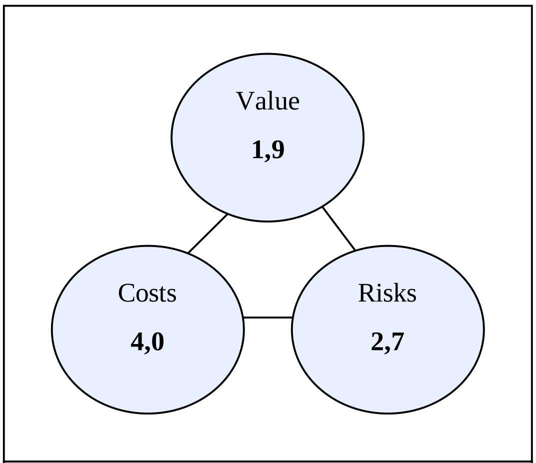
2-5 Do you think that the adoption of energy-efficient technologies is important [for your company] for the following reasons?
Classify in ascending order (1 = the least important – 5 = the most important)

- **2_5_3 Risks reduction** ____________
  Please specify which ones ______________________________
- **2_5_4 Costs reduction** ____________
  Please specify which ones ______________________________
- **2_5_5 Products value increase** ____________
  Please specify which ones ______________________________

Annex 2 – Strategic character of energy-efficiency investments for energy and finance managers



"Strategicity" for energy managers: **9,1 on 15**



"Strategicity" for finance managers : **8,6 on 15**

Annex 3 – Simplified energy management audit

3.2 Energy intensity: which percentage do your energy consumption total costs represent ?
2 points (if at least one answer)

- Percentage of your general expenses ? ___________ % O Not calculated
- Percentage of your turnover ___________ % O Not calculated
- Percentage of your profit? ___________ % O Not calculated

3.5 Did your company make a commitment of a continuous reduction of its energy consumption ? O Yes O No
2 points

3.6 Did your company undertake any of the following tasks in relation with energy use?
(please mark appropriate cases) **8 points**

O Evaluation of energy performance (benchmarking)
O Definition of a baseline
O Definition of key performance indicators
O Definition of energy policy
O Setting of measurable goals regarding energy consumption reduction
O Data collection regarding goals achievement
O Definition and setting of measures to reach the goals defined

3.7 Which resources have been allocated to energy-efficiency measures implementation? (please mark the appropriate cases) **3 points**

O Human resources (i.e. project team)
O Technical resources (i,e meters)
O Electronic resources (i.e. software)

3.8 Does the company have an energy manager ? O Yes O No
2 points

3.9 Does the energy manager perform other functions in your company?
O Yes O No
If yes, which one ? ____ **-1 point**

3.10 Does your company establish an internal communication on energy issues (i.e. report)?
O Yes O No
1 point

3.11 Did your company organize the following systems and procedures in relation with its energy policy: (please mark the appropriate cases) **4 points**

O training system for staff
O reward system
O monitoring system of the results in goals reaching
O revising goals procedure ?

1 point by positive answer, 2 points by positive answer to questions 3.2, 3.5, 3.6.3 et 3.8 (but 1 point is deducted in case of a positive answer to question 3.9). Maximum score: 22 points.

Lighthouse programme for high-efficiency commercial buildings in Upper Austria

Christiane Egger

Deputy Manager, O.Ö. Energiesparverband

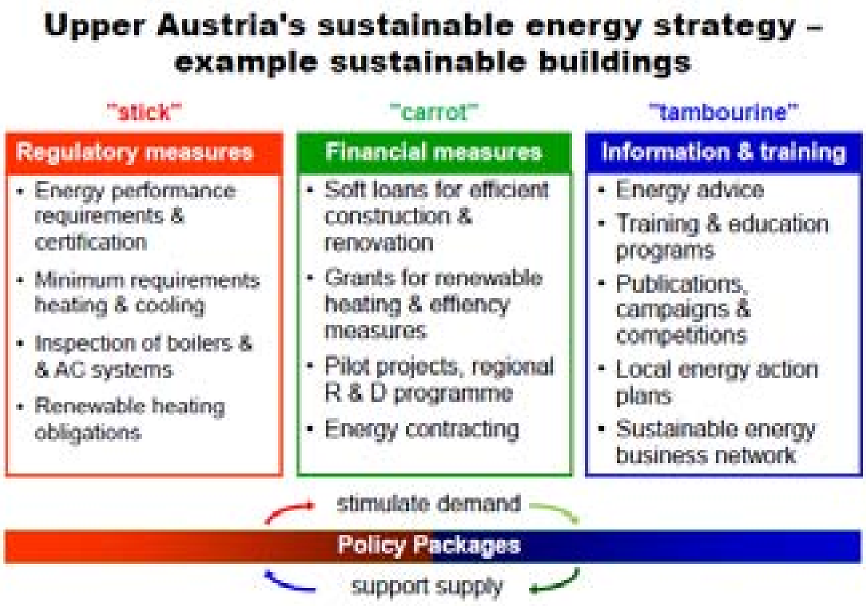
Abstract

Upper Austria is a leading European region in sustainable buildings. Due to consistent policies, today there are more than 1,000 buildings meeting passive building standard and several thousand "lowest energy buildings". However, so far this development took place mainly in the residential sector. That is why a pilot programme supporting the construction of lighthouse projects in the field of commercial buildings was carried out showcasing innovative technologies. The programme was managed by the O.Ö. Energiesparverband, the energy agency of Upper Austria, in cooperation with the regional administration.

Background

Since the mid-90s, the government of Upper Austria has prioritised energy efficiency and renewable energy. Renewable energy currently supplies 34% of the total primary energy demand in the region. The share of renewables in the energy mix was achieved through comprehensive regional energy action plans that laid the foundation for more than a decade of steady progress. Building upon the success of its policies to date, Upper Austria has set a target to meet 100% of its electricity and space heat demand by renewable energy sources. and to reduce energy consumption for heating by 39% and CO_2 emissions by 65% by 2030.

To achieve its ambitious goals, Upper Austria has developed policy packages for different target groups. These packages consist of financial incentives (mostly investment grants), legislation to mandate installation obligations, and promotional activities (energy advice, outreach campaigns, training, etc.). The different types of support mechanisms can be thought of, respectively, as carrots, sticks, and tambourines. The O.O. Energiesparverband is in charge of implementing many of these programmes and providing related services.



The O.O. Energiesparverband also manages the “Okoenergie-Cluster“, the network of renewable energy and energy efficiency companies in the state. There are currently 160 companies and institutions in the network, which employ more than 7,300 people and generate annual revenues of more than 1.8 billion Euro. The network members represent the full spectrum of sustainable energy products and services and high-efficiency building technologies. In recent years, companies in these fields have experienced strong growth and have added more than 500 new jobs in the region.

Approach

The lighthouse programme was developed and implemented to support the construction of new high-efficient commercial buildings (> 300 m²). 7 selected pilot projects, most of them passive house buildings, received a grant of up to 100,000 Euro. This subsidy should cover the additional costs for energy efficient planning and investment. For the selection process a tender was carried out.

In addition the companies were supported by the energy advice service operated by the O.Ö. Energiesparverband, where annually about 300 energy advice sessions for companies are carried out on-spot.

Pilot Programme Elements

The aim of the pilot programme was to demonstrate energy innovation in the field of commercial buildings. In The following criteria were used in the tendering process:

- ambitious energy performance indicators for heating, cooling, lighting
- innovative technologies
- obligatory use of renewable energy sources for heating
- electricity efficiency measures to reduce internal loads (e.g. use of day light, efficient lighting and appliances)
- use of environmentally friendly building materials, healthy indoor climate
- measures to include building users (awareness raising, user behaviour)
- companies received advice and were supported through the project development process.

A comprehensive information campaign was carried out by the O.Ö. Energiesparverband, including several information events, targeted mailings and press activities.

This campaign was carried out in the framework of the comprehensive programme of the O.Ö. Energiesparverband to promote energy efficiency and renewable energy sources in commercial buildings. These include:

- *Energy and auditing service*:
  energy advice service for companies (annually about 300 advice sessions for companies are carried out)
- *Information & awareness raising activities*:
  publications, events and targeted campaigns
- *Training:*
  training course "energy efficient cooling", training seminar "energy advice and energy management for companies"

- *"Ökoenergie-Cluster" (OEC):*
  network of green energy businesses (160 companies, € 1,800 million/a turn-over, 7,300 employees) supporting business development

- *Energy Contracting:*
  regional third party financing programme for energy efficiency investment in companies

- *R&D:*
  technical and financial support is provided by the regional energy technology programme

- *European projects:* e.g. e-tools, Buy smart

- *EPBD Campaign:*
  3 large information events with 1,050 participants, training courses: 12 courses, 280 participants publications "EPBD implementation in Upper Austria", 15,000 copies, 60+ presentations to different stakeholder groups (e.g. banks, professional associations, building component producers), 100+ press articles in the regional press

- *Online tools:*
  In order to support electricity efficiency in tertiary sector buildings, two online tools were developed, which help to analyse and monitor electricity consumption especially in office buildings.

Legal measures

In order to trigger efficient commercial buildings, the following legal measures were taken:

- *Legal measures to decrease the cooling demand for non-residential buildings (new & complete renovation):*
  - either "proof of prevention of summer overheating" (ÖNORM-B 8110-3)
  - or "max. externally-induced cooling demand":
  - max. • 1 kWh/m^2a (new construction)
  - max. • 2 kWh/m^2a (complete renovation)

- obligation for measures against summer overheating

- regular inspections of heating and cooling systems

- priority for renewables for new buildings > 1,000 m^2

Examples of innovative commercial buildings realised under the pilot programme

Among others, the following commercial buildings were realized under the pilot programme:

Peneder	**pictures**
new office building (11,013 m^2)	
heating demand: 3.45 kWh/m^3,a; cooling demand: 0.74 kWh/m^3,a	
innovative technologies: heat and cold produced from wood chips; innovative daylight concept	

Revital	
hotel, health centre (4,619 + 723 m^2)	
heating demand: 2.37 kWh/m^3,a; cooling demand: 0.99 kWh/m^3,a	
innovative technologies: solar cooling; energy efficient ventilation pumps; energy efficient lighting (LEDs, innovative control system); user participation programme (environmental staff team, information of guests)	
PAUAT Architekten	
construction of the office building and retrofitting of an existing building (503 m^2)	
heating demand: 2.24 kWh/m^3,a; cooling demand: 0.93 kWh/m^3,a	
innovative technologies: passive house building standard, 3 photovoltaic systems (4.8 kWp each), 18 m^2 solar thermal collectors	
Isolenawolle Naturfaservliese	
company hall, show room, lounges, offices (404 m^2 offices + 788 m^2 hall)	
heating demand: 7.60 kWh/m^3,a; cooling demand: 0.17 kWh/m^3,a	
innovative technologies: sheep wool insulation, efficient use of day light, innovative control system, biomass heating, thermal solar collectors, use of rain water	

Conclusions

With the support of the lighthouse programme, it was possible to realise several highly ambitious lighthouse buildings which are now very useful in promoting the concept of "nearly zero energy buildings" in the commercial sector. Unfortunately, due to the economic crisis, not all selected buildings were realised. For the future, the long-term impact of the lighthouse programme will depend on continued pro-active dissemination actions.

References

[1] Dell G.: *Die Umsetzung des OÖ. Energiekonzeptes.* Berichtsjahr 2010 (Linz, Austria, April 2012). Can be ordered from www.esv.or.at

[2] Dell G.: *Energiezukunft 2030. Die oberösterreichische Energiestrategie* (Linz, Austria, June 2009).Can be ordered from www.esv.or.at

[3] Egger C., Öhlinger C.: *Biomass heating in Upper Austria. Green Energy, green jobs* (Linz, Austria, July 2010). Can be ordered from www.esv.or.at

[4] Egger C., Öhlinger C.: *Carrots, Sticks and Tambourines: How Upper Austria became the World's Leading Solar Thermal Market* (Linz, Austria, July 2010). Can be ordered from www.esv.or.at

[5] FOREST: *Partnerships for Success* (2010). Can be ordered from www.forestprogramme.com

The Energy Navigator – A Web-Platform for Performance Design and Management

Plesser, Stefan[1], Claas Pinkernell[1], Norbert M. Fisch[2], Bernhard Rumpe[3]

[1] synavision GmbH, Aachen
Braunschweig University of Technology,

[2] Institute of Building Services and Energy Design,
Braunschweig University of Technology,

[3] Software Engineering
Department of Computer Science 3
RWTH Aachen University

Abstract

Over the last three decades comprehensive research has been carried out trying to improve commissioning processes with powerful modeling tools and methodologies for data analysis and visualization. Typically addressed application scenarios are facilities management, contracting, special consulting services and measurement & verification as part of a certification process. The results are all but convincing: Monitoring of building operation has so far not become a regular service for buildings.

We have identified a lack of process integration as a significant barrier for market success. Most methodologies have so far caused additional initial invest and transaction cost: they added new services instead of improving existing ones. The Energy Navigator, developed by synavision GmbH in cooperation with leading research institutes of the Technical University Braunschweig and the RWTH Aachen University, presents a new methodology with several new approaches. Its software platform uses state graphs and a domain specific language to describe building functions offering an alternative to the software that is so far most widely used for this task: Microsoft Word.

The Energy Navigators so called Active Functional Specification (AFS) is used for the technical specification of building services in the design phase. After construction it is completed by the supplier of the BMS (Building Management System) with the relevant sensors data as documentation of his service. Operation data can then automatically be checked for initial and continuous commissioning on whether it meets the criteria of the specification. First real life applications have shown that the Energy Navigator offers a software solution that can be applied by actually simplifying existing building processes, by improving documentation of building services and by providing an automated control of building operations.

Research shows that good operations are essential for sustainable buildings. By providing a standardized functional commissioning process and a state-of-the-art web platform for building services without significant additional cost the Energy Navigator promises to be a breakthrough for quality in building operations.

1. INTRODUCTION

Energy efficiency of buildings depends on their hardware – their construction, insulation, glazing, HVAC systems etc. – and on the way they are used and operated. While politics and technical guidelines as well as the historically developed procedures focused on hardware to improve energy efficiency, the software – user awareness, monitoring, commissioning – is now being moved into the spot light in Germany.

Technical guidelines like DIN EN 15232 [1] help to evaluate the potential increase in energy efficiency by using new building management technologies and algorithms. The guideline defines different BMS solutions that allow an easy A-D classification for different building services with a corresponding saving potential percentage.

Beyond the building design for the first time mandatory codes such as EnEV 2009 [2] require not only a certain level of energy efficiency on the basis of a calculated energy demand using models like defined by DIN V 18599 [3]: During the life cycle large air conditioning systems have to be inspected regularly every 10 years.

DIN EN 16001 [4] goes beyond these technical recommendations by defining an overall controlling process for building owners, public administration or businesses. It helps to establish a process of installing a monitoring system, gathering and analysing data, reporting, defining the responsibilities within the institution and the documentation of savings. The whole process is supposed to be part of a wider sustainability strategy. Its implementation is a criterion to receive tax reduction thereby providing cost savings even without immediate cuts in energy consumption. While commissioning is already strongly regulated by German building laws and defined by technical guidelines like VDI 6022 [5], DIN 15239 [6], 15240 [7] and others, it is further strengthened by certification labels by the German *DGNB – Deutsche Gesellschaft Nachhaltiges Bauen* or the *US American LEED-Standard*. Both require commissioning and monitoring actions to improve building operations including functional performance testing.

The target of any commissioning and monitoring regarding building operations is to optimize the functions of the building in operation. Although it is obvious that functions in operation must have their roots in the functional design of buildings the majority of publications in this field focuses on BMS data analysis, fault detection in operation and successful re-commissioning in the later operations. A good survey on approaches is given by Katipamula [8] and the IEA Annex 47 reports [9]. There is no research work to our knowledge that focuses explicitly on the way a functional description is actually being used after the design phase to monitor operations and serve as adaptable part of the building documentation. This aspect becomes even more important when innovative buildings are individually designed and undergo comprehensive operational adjustments in the first year of operation.

Crucial for the large scale success of monitoring buildings in operation as well as for stronger political measures requiring monitoring are cost effective solutions. Therefore the starting point for the Energy Navigator was not the technical opportunities that the internet and Building Management system (BMS) provide to analyze data. The innovative approach started by checking what is needed to ensure good building performance.

2. BASICS SOFTWARE TECHNOLOGIES

The Energy Navigator is a technical state of the art software platform, using client- server mechanisms, providing the possibility to not only monitor but also specify the behavior of a BMS. The platform provides all means necessary to get a closed circuit between specification, monitoring, data analyses and optimization. Monitoring of buildings and providing sophisticated analyses means handling mass data. The platform is able to collect either automatic, by using OPC to directly read values from the BMS, or manual, by importing data from a data logger, in discrete intervals. Since we created a highly adaptable platform we are able to scale up the data collection to one data point each second for a single sensor. But under normal conditions a resolution of collecting one data point every 15 minutes for a single sensor has proven to be feasible and state of the art in building automation systems. Even this coarse grained data collection leads to a lot of information that needs to be stored and processed by the platform. Consider a building having 1000 sensors each producing a data point every 15 minutes. Thus we get 96000 data points a day from a single building being about 35 million data points a year. To keep the performance and scalability we use cloud computing based storage techniques. Additionally most modern building automation systems provide the possibility to not only log data points but to log also markers signaling different modes a building or part of it resides in.

Each data collection is followed by a preprocessing step ensuring that all the values have equidistant timestamps and filtering outlier. Having collected all the data the user needs to be able to create custom analyses for the monitored building. To support these tasks the Energy Navigator platform provides the possibility to create several elements aiding the analyses of mass data measured in a building. We therefore created a Domain Specific Language (Karsai et al., 2009 [13]) for specifying and modeling buildings. To create such a language we use our framework MontiCore (Krahn et al., 2010 [14]). The language and basic application principles have been described in (Fisch, Plesser et al., 2010, 2011 [15]).

The Energy-Navigator Platform is divided into a client side that can be web based or desktop based. The web based client concentrates on visualization of reports for end users of a building (management reports, public awareness). The rich client is used by energy experts that specify, evaluate and validate the proper operation of a building. The platform is designed for multiuser access, figure 1.

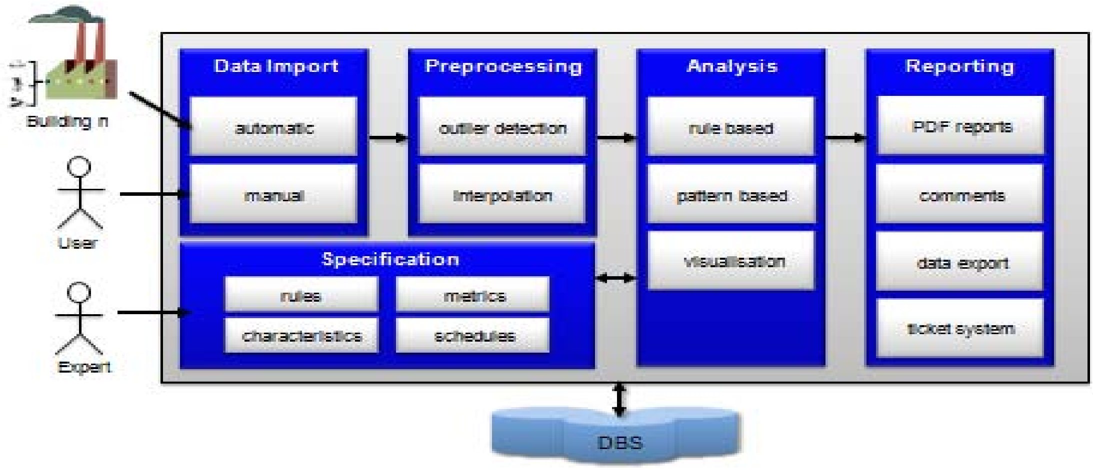


Figure 1 **Software architecture of Energy Navigator platform**

On the server side there are several components forming the backend platform. Each component can be plugged in, so that the platform is highly adoptable to build complex solution for each building. The components are grouped into Data Import, Preprocessing, Analysis, Report and Specification. The platform offers automatic or manual (file based) import depending on the data availability inside the building system. After the import data can be automatically preprocessed. This is a crucial step to guarantee a high data quality for analysis and further calculations. There is outliner detection or interpolation of missing values, a transformation to equidistant time steps, to mention only some preprocessing workflows. The analysis can be done automatically by using a formal specification model and intelligent algorithms. Additionally an energy expert can use the platform to visualize the imported data with multiple plot types, e.g. line plots, scatter plots or carpet plots. Another feature of the Energy-Navigator Platform is the reporting component. With this component we are able to automatically create reports and inform other users about the current system status, and potential performance issues of the building.

The platform uses a database backend and high efficient algorithms that are optimized to handle mass data of current building systems. The data can be processed and stored localized, e.g. for reasons of data privacy protection, or with innovative cloud computing technologies for better scalability and resource sharing.

3. ACTIVE FUNCTIONAL DESCRIPTIONS USING THE DOMAIN SPECIFIC LANGUAGE

A crucial aspect is how to deal with complexity in the design of buildings. The Energy Navigator platform establishes the concept of templates for every artifact. The idea behind this concept is that an expert can specify his/her knowledge once at the beginning and use these templates easily for every building that he/she operates or manages. For a concrete building the expert adds the templates to the workspace and maps the concrete sensors to the template. The use of a library is a key feature for reusability of expert knowledge.

The main concept of the Energy Navigator platform is a constraint language that is used to specify facilities, systems and building operation. The constraint language is an adapted variant of the Object Constraint Language (OCL), part of the well-known Unified Modeling Language (UML). [16] The language is developed with MontiCore [17] -a framework for efficient language design. The main artifacts of the language are rules, functions, metrics, time routines and characteristics. The concepts can be described as follows:

Rules

Rules are logical and arithmetical expressions [18] that can be evaluated to Boolean values true or false. They are defined in the context of sensors and can be used to specify the desired behavior of a system.

A rule may contain logical operators like AND, OR, IMPLIES, NOT, IF-THEN-ELSE etc. and arithmetical operators like PLUS, MINUS, MULTIPLY, DIVIDE etc. An important concept to deal with complexity of such specifications is referencing sub rules or other language elements, like functions from a library (e.g., MAXIMUM, SUM, AVERAGE etc.). The referenced elements are specified self-contained in separate artifacts to enable reusability within other language artifacts.

After specifying a rule an automated analysis can be executed by the platform. For each rule (and sub element) a virtual sensor is created. A virtual sensor is analogous to real sensors an equidistant sequence of values. In the case of a rule a valid value can be true, false, missing or undefined. A result is missing if no context information (sensor data) is given. An undefined result means that no evaluation was possible. The resulting sequence has the same temporal resolution as the context sensors, for instance 15 minutes.

Functions

Functions are very similar to rules but they are not resulting in Boolean but numeric values. The context of a function is one or more real or virtual sensor. An example with two sensors is the function f(s1, s2) = s1 - s2 where s1 could be the supply temperature and s2 the return temperature in a heating circuit. The function calculates the temperature spread, which can directly be used for visualization or can be referenced in other functions, rules or metrics.

Characteristics

Characteristics are a powerful concept to specify relations between two sensor dimensions. A single characteristic or an upper and lower characteristic can be specified by a point based graphical editor. The characteristic can be defined as a function or as a rule.

Metrics

Functions, rules and characteristics are equidistantly processes, what means that the value sequences are iterated from timestamp to timestamp and results are calculated by the given parameters. Compared to functions metrics are calculating values for a given time span for example the energy consumption of one month or an average daily temperature.

A so called base metric consists of a context sensor, for example a temperature measurement every 15 minutes. Additionally a base function can be added, for example Average, Minimum, Miximum, Sum etc. Last but not least a time quantization can be added. At this stage the system supports Day, Week, Month, Quarter and Year.

With this simple configuration mechanism a lot of standard metrics can be calculated. Additionally customized metrics can be used from a library which can be parameterized, e.g. the calculation of a standard deviation. Metrics are very helpful for management reports.

Time Routines

Time routines can be used to differentiate between several operations modes. An example for use is the specification of a public school building, where facilities should have different operation modes for weekdays, weekends or holidays. A time routine can be defined a set of time ranges. Values for year, month, day, hour, minute, second and weekday can summarized to a schedule. It is also possible to include or exclude additional time routines to specify exception, e.g., holidays.

Ticket System

The ticket system is highly adoptable for each building. It can be used for our automatic and manual analysis of the building data. After a rule was evaluated by our system and failed because the facility is not running conform to the specification, we create a new ticket that holds all necessary information for the facility manager. So violated constrains or specifications from the design phase can be traced during the operation of a building.

Visualization

Our platform offers several types of visualization. We can use line plots, scatter plots and carpet plots as shown in figure 2, figure3 and figure 5.

Reporting

After the analysis we offer the automated generation of reports. These reports are customizable. It is possible to insert handwritten parts to the generated reports. So an energy expert can create a special purpose report which focuses only on the heating facilities of a building that consists only of the important sensors, facilities, rules and visualized plots. This report can then be reused for a specific building. The expert can make additional comments, e.g. to give suggestions what should be changed for the operation of the heating facilities. These comments are saved independent of the generated report. If the report is regenerated, e.g. after one month new operational data of the building is available; the original handwritten comments are still there.

4. NEW WAYS TO DESIGN AND REPORT FUNCTIONAL QUALITY

Conventional analysis and reporting rely on operation data only. Typical graphs of energy information simply state the energy consumption of buildings for past periods of time, sometimes aggregated to create a kind of energy accounting, figure 2.

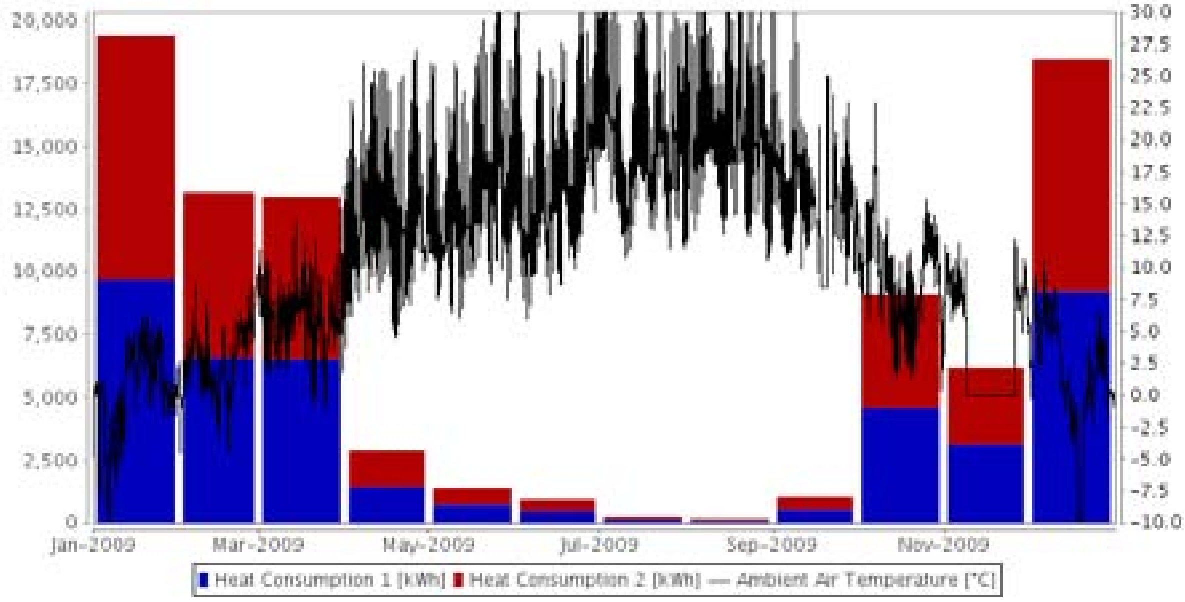


Figure 2 **Example graph: historic data for monthly energy consumption**

More sophisticated tools for data analysis provide graphs to visually examine large amounts of data in short time. The power of these tools in practical application, as shown in figure 3, depend heavily on the expert knowledge and motivation of the user since they need precise technical understanding and interpretation.

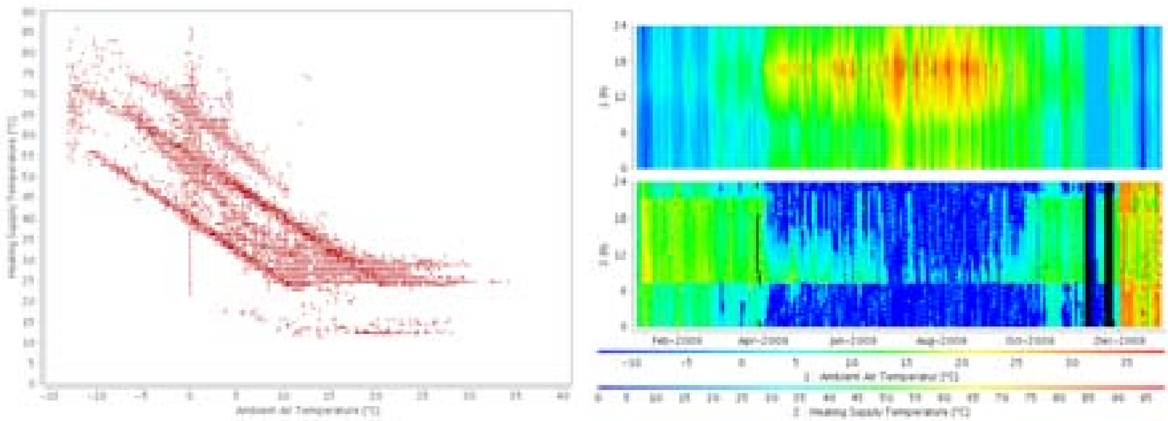


Figure 3 **Example graph: visualization techniques for easy analysis of building operations**

Advanced tools use modeling techniques to define a target or limit value. Most common are *black box models*, usually based on historic data from the building or system that has been transformed into predicted values for the operation data by statistic modeling, or *white box models* in which physical and technical knowledge is applied in dynamic simulation tools to model a target value. Most common are target values for the total heat and electricity consumption of buildings. Easy models can also be used for simple limit checking e.g. of load curves or temperatures.

The Energy Navigator uses the active functional specification (AFS) as modeling methodology using the domain specific language in combination with technical schematics of the corresponding system as shown in figure 4.

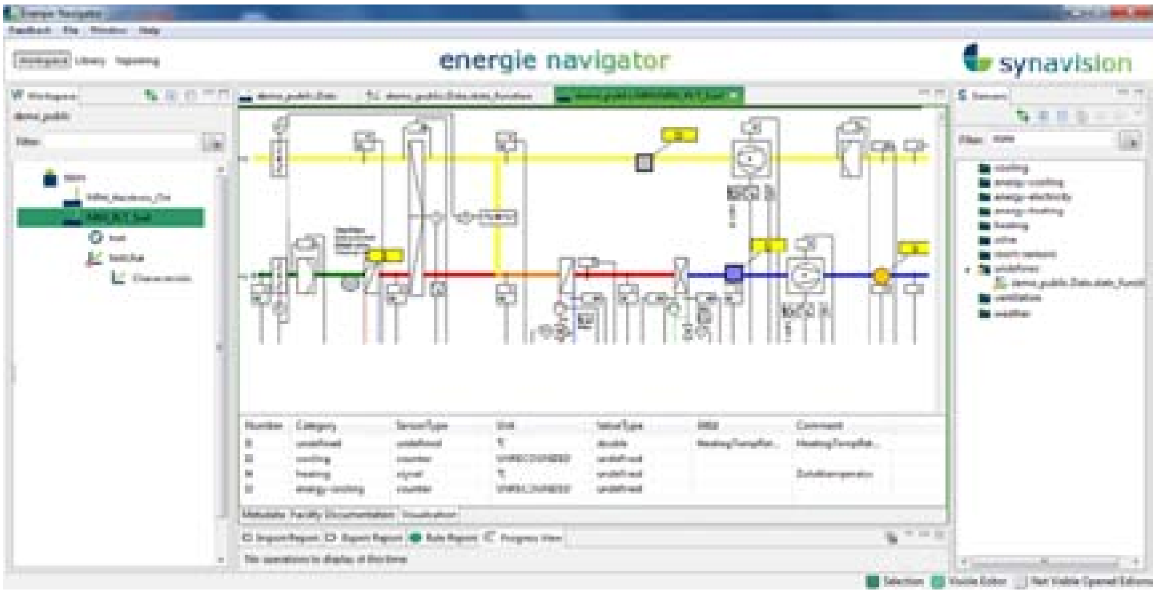


Figure 4 **Active Specification of the Energy Navigator platform**

The graphical editor helps to easily match the design specification and the operation data. The concept has some promising advantages:

- The specification is not only used for the “checking” in operation but already for the “explaining” of the intended function in the design phase. This improves communication within the project especially in complex and individual buildings.
- Since the specification is “online” it can be expanded and adjusted during the life cycle keeping the documentation of the building up to date.
- By defining a target value in the design phase the building owner can not only check operation later on automatically. The specified function can be part of the contract for the BMS contractor: performance becomes a measureable part of the service.

Although all the graph that have been mentioned above are also possible, the key graph shows red or green for each point of time indicating correct or incorrect performance compared to the specification, figure 5.

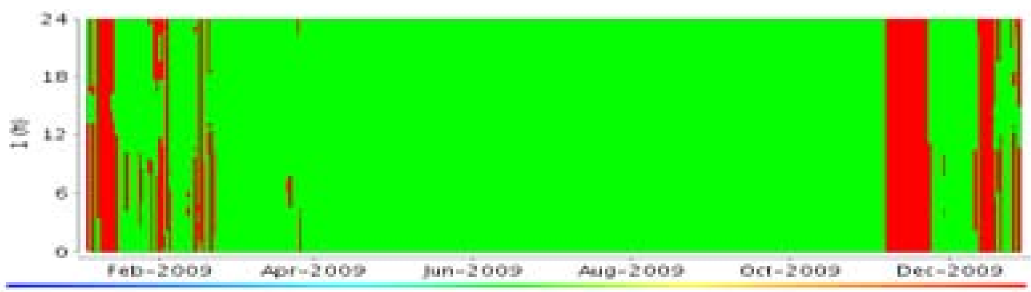


Figure 5 **Checking the performance: green indicates correct performance, red indicates malfunction**

In addition to the graph the information behind it can be used to create tickets, emails, SMS or any other kind of reporting with web 2.0 technologies.

5. TURNING BUILDING CONCEPTS INTO BUILDING PERFORMANCE

The Energie-Navigator provides new opportunities for buildings in design, construction and operation. The platform is web-based, easy to apply and its application therefore feasible for all partners during the whole life cycle. Since all partners work in the same environment, the system guarantees means for a continuous use thereby bridging the gap between design and operation phase, figure 6.

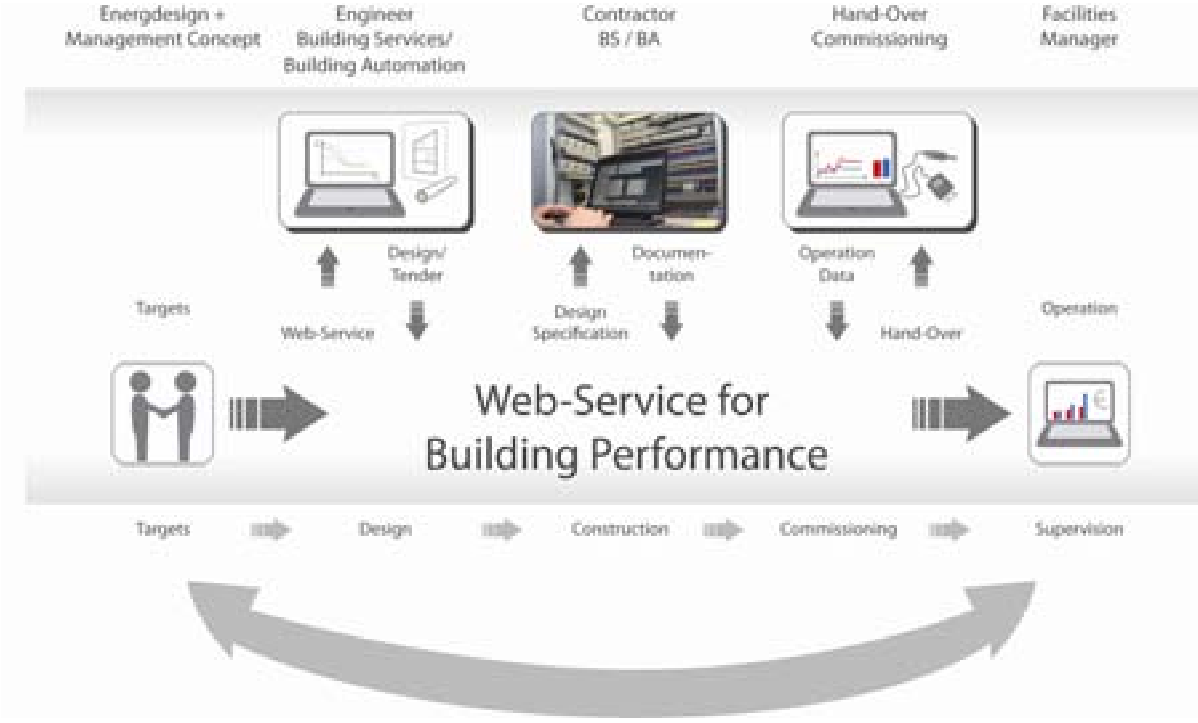


Figure 6 **Project workflow for the Energy Navigator**

By integrating a powerful tool into the existing workflows in today projects and providing a language for the specification of building functions the Energy Navigator promises to powerfully help to turn energy efficient building concepts into truly energy efficient buildings.

We are finishing the initial testing of the application and have founded the synavision GmbH (www.synavision.de) that will bring the Energy Navigator on the market as a software product in 2012.

References

[1] DIN 15232: Energieeffizienz von Gebäuden - Einfluss von Gebäudeautomation und Gebäudemanagement; Deutsche Fassung EN 15232:2007-11

[2] EnEV 2009: Energieeinsparverordnung 2009

[3] DIN V 18599: Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung, 2007-02

[4] DIN EN 16001: „Energiemanagementsysteme", 2009-08

[5] VDI 6022: Technische Regel, Hygiene-Anforderungen an Raumlufttechnische Anlagen und Geräte, 2006-04

[6] DIN EN 15239: Lüftung von Gebäuden - Gesamtenergieeffizienz von Gebäuden - Leitlinien für die Inspektion von Lüftungsanlagen; Deutsche Fassung EN 15239:2007

[7] DIN EN 15240: Lüftung von Gebäuden - Gesamtenergieeffizienz von Gebäuden - Leitlinien für die Inspektion von Klimaanlagen; Deutsche Fassung EN 15240:2007

[8] Katipamula, S, Brambley, M.: Methods for Fault Detection, Diagnostics, and Prognostics for Building Systems-A Review, Part I, HVAC&R RESEARCH, VOLUME 11, NUMBER 1, 2005-01

[9] See http://www.iea-annex47.org/

[10] Karsai, G., Krahn, H., Pinkernell, C., Rumpe, B., Schindler, M. and Völkel, S. 2009. *Design Guidelines for Domain Specific Languages*. In: Proceedings of the 9th OOPSLA Workshop on Domain-Specific Modeling (DSM' 09) Helsinki School of Economics. TR no B-108. Orlando, Florida, USA.

[11] Krahn, H., Rumpe, B. and Völkel, S. 2010. *MontiCore: a Framework for Compositional Development of Domain Specific Languages.* In: International Journal on Software Tools for Technology Transfer (STTT), Volume 12, Issue 5, pp. 353-372.

[12] Fisch, M. N.; Plesser, S., et al.: „EVA - Evaluierung von Energiekonzepten für Bürogebäude": (Gesamt-) Abschlussbericht. Braunschweig / Hannover, Technische Informationsbibliothek u. Universitätsbibliothek, 2007

[13] Karsai, G., Krahn, H., Pinkernell, C., Rumpe, B., Schindler, M. and Völkel, S. 2009. *Design Guidelines for Domain Specific Languages*. In: Proceedings of the 9th OOPSLA Workshop on Domain-Specific Modeling (DSM' 09) Helsinki School of Economics. TR no B-108. Orlando, Florida, USA.

[14] Krahn, H., Rumpe, B. and Völkel, S. 2010. *MontiCore: a Framework for Compositional Development of Domain Specific Languages.* In: International Journal on Software Tools for Technology Transfer (STTT), Volume 12, Issue 5, pp. 353-372.

[15] Fisch, M. N.; Plesser, S., et al.: „EVA - Evaluierung von Energiekonzepten für Bürogebäude": (Gesamt-) Abschlussbericht. Braunschweig / Hannover, Technische Informationsbibliothek u. Universitätsbibliothek, 2007

[16] OMG: OMG Unified Modeling Language Specification. Technical Report, Object Management Group (2003)

[17] Krahn, H.: MontiCore: Agile Entwicklung von domänenspezifischen Sprachen im Software-Engineering. Shaker, Aachen (2010)

[18] Rumpe, B.: Modellierung mit UML. Springer, Berlin (2004)

Future low-energy office buildings in Sweden

- Reduced heating, cooling and electricity

Kajsa Flodberg, Åke Blomsterberg, Marie-Claude Dubois

Lund University, Energy and Building Design

Abstract

The paper presents the results of dynamic simulations of energy use that have been carried out with the software IDA ICE on a typical office building with perimeter cell rooms. Within these simulations, different parameters were studied in order to see how they affect heating, cooling and electricity intensity. The parameters studied were insulation levels, airtightness, thermal mass, glazing-to-wall ratios, solar shading and control, lighting dimming and control, office equipment and control, passive cooling and ventilation strategies. The results show that glazing-to-wall ratio, ventilation strategies and lighting control strategies have a large impact on the energy use, whereas thermal mass have a relatively small effect. The best practice of all parameters and scenarios were combined in a holistic approach, which yields a total end-use energy of 71 kWh/m²,yr (heating 24, facility electricity 14, tenants' electricity 29 and cooling 4 kWh/m²,yr). Thus, it is possible, using a combination of simple and well-known building technologies and configurations, to have very low energy use in new office buildings, for the same cost as traditional constructions. The study provides a strong basis supporting design guidelines for architects and engineers, who will build and refurbish tomorrow's very low energy offices. One aspect of the results concerns tenants' electricity, which becomes a major energy post in very low energy offices and which is rarely regulated in building codes in Northern Europe today. This results not only in high electricity use, but also in large internal heat gains and unnecessary high cooling loads given the high latitude and cold climate.

1. Introduction

The energy consumption in office buildings is generally high compared to other building types. For example, the most recent statistics for Sweden [1] show that the total delivered energy (end energy) to existing office buildings was around 210 kWh/m² in 2007, whereof half was electricity and half district heating and cooling. Regarding new office buildings, the energy performance has been improved in terms of reduced heating loads, but the electricity for lighting and equipment is still high. High electricity results in large primary energy demands in general and also in internal heat gains and heat surplus leading to unnecessary cooling loads given the high latitude and cold climate.

Good examples of low-energy and nearly zero-energy residential houses have been built in Sweden during the past decade [2-3]. However, there is no example of a nearly zero-energy office building. In Germany, on the other hand, a number of passive and low-energy office buildings has been constructed and evaluated [4-5]. Also, research on energy efficiency potential for a passive office building has been carried out with dynamic simulations by Knissel [6]. These German experiences are clearly important for the development of future zero-energy office buildings. However, German building techniques must be developed to adapt to the Swedish context, as climate conditions and indoor comfort criteria differ between the countries. In order to bridge this gap, the project '*Energy-efficient office buildings with low internal heat gains: simulations and design guidelines*' was initiated. This project aims to provide knowledge to the Swedish building industry, supporting the development of cost-effective office buildings with good indoor climate and very low energy use. The main goal is to reduce the annual energy use by 50%, compared to the requirements in the Swedish building code. This paper describes the second phase of the project, which investigates how to design low-energy office buildings that are optimal for Swedish conditions. Cost effectiveness is considered, in a way, by using proven techniques that are available on the market today. This paper presents dynamic simulations of a typical office building, performed with the software IDA ICE 4. Important design features are revealed in a parametric study, and the goal is to achieve an office building with a good indoor climate, which uses less than half the energy compared to a new office building, including user related electricity. The paper discusses recommendations and design guidelines for architects and engineers, regarding the design of future low-energy office buildings.

2. Method

Dynamic simulations were recently carried out within the project, on a model of a typical narrow office building with perimeter cell rooms. The overall method and results are presented in this paper as well as an additional sensitivity study investigating the impact of location and office operation. More details can be seen in [7]. The simulations were carried out with IDA ICE 4, a dynamic multi-zone simulation program for study of indoor climate of individual zones within a building, as well as whole-year energy consumption for the entire building. It uses the neutral model format (NMF) language and hence enables the user to change and write new models. IDA ICE was developed in the mid-eighties at the Royal Institute of Technology (KTH) in Stockholm, Sweden and now serves a global market. IDA ICE is the probably the most frequently used tool for energy simulations of non-residential buildings and low-energy houses in Sweden today. Thus, the program was selected for this study even though it is rather complex and not considered optimal for multi-zone parametric studies.The simulation tool is provided by EQUA Solutions AB and it has been validated according to CEN 13791, ASHRAE 140-2004, CEN 15255, CEN 15265, CIBSE TM33, RADTEST and Envelope BESTEST [8].

IDA ICE handles a number of different features and can be used for calculation of:

- Full zone heat and moisture balance with contributions from solar radiation, occupants, equipment, lighting, ventilation, heating and cooling devices, heat transmissions, thermal mass effects, air leakage, cold bridges and furniture
- Wind and buoyancy driven airflows through leaks and openings
- Air and surface temperatures and operative temperature at any occupant location
- Temperature, CO_2 and moisture levels which can be used for controlling the air handling system
- Solar influx thorough windows and the influence of local shading devices and surrounding buildings
- Daylight level at any room location
- Comfort indices (PPD and PMV)
- Energy cost (based on time-dependent prices)

2.1 The base case

In the simulation study, a reference building was modelled as a base case, designed to correspond to the current energy regulations in the Swedish building code BBR 18 [9]. The virtual reference building is a typical large office building with single office rooms along the facades and a central core with stairways, elevators and other facilities. The building is a six storey building with a narrow shape (approximately 66 m x 16 m) with the short sides orientated to east and west (see Figure 1 and 2) [10]. The room height is 3.2 m and the floor height is 3.5 m with 0.3 m concrete intermediate floors and a thin ceiling. Each floor is 1030 m^2 with a total heated net floor area of 6180 m^2. More building data can be seen in Table 1. The data is to a great extent in line with the standardized input parameters for energy calculations in office buildings (Sveby) provided by the Swedish Property Federation [11].

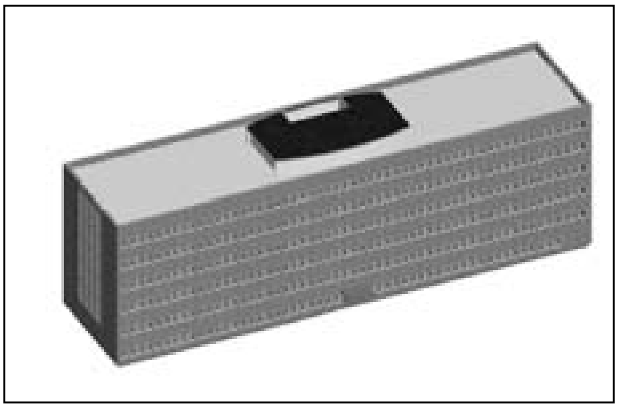


Figure 1. The reference building [10]

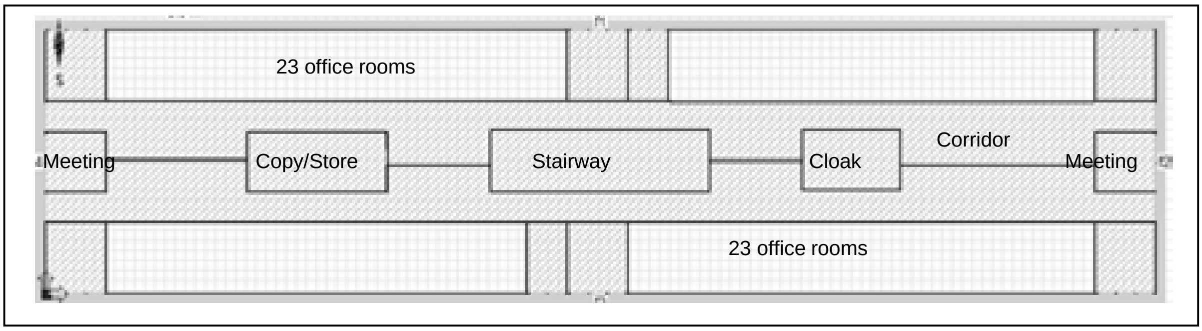


Figure 2. A typical floor plan with thermal zones modelled in IDA ICE

Table 1. Base case data

Parameter		Simulation input	Comment
Climate conditions	Location	Stockholm 59.35N, 17.95E	
	Temperature Dry-bulb min/mean/max	-18.3 / 6.5 / 26.1 •C	ASHRAE Fundamentals 2001
	Horizon angle	15•	EN ISO 13790:2008
Dimensions	Heated net floor area (A_{temp})	6 180 m^2	BBR definition
	Air volume	19 776 m^3	
	Envelope surface	5 193 m^2	
	Façade surface	3 133 m^2	
	Glazing-to-wall ratio (GWR)	31%	(window-to-wall-ratio 35%)
	Window-to-floor ratio (WFR)	18%	
Building elements	External wall U-value	0.20 W/m^2 •C	170+50 mm mineral wool
	External roof U-value	0.11 W/m^2 •C	300 mm mineral wool
	External floor U-value (excluding ground resistance)	0.17 W/m^2•C	200 mm EPS
	Windows U-value (including frames)	1.4 W/m^2 •C	Pilkington Suncool 2-glass
	Glazing	LT 72%, SHGC 43%	Pilkington Suncool 70/40
	Internal blinds	0.83	SHGC multiplier
	Total UA transmission	2119 W/•C	
	Thermal bridges	445 W/•C, 21% of total UA	Calculated with HEAT2 [12]
	Air leakage rate	1.5 ach (n_{50})	EN 13829:2000
Heating/cooling	Boiler COP	0.9	
	Heating coil COP	0.9	In air handling unit
	Domestic hot water COP	0.9	
	Domestic hot water	2.0 kWh/m^2yr	Sveby standard
	Chiller COP	0.9	
	Cooling coil COP	0.9	In air handling unit
Thermal climate	Set points for mean air temperature	22-23•C	Normal target values
Ventilation	Ventilation operating hours	Weekdays 7:00-19:00	
	Constant Air Volume	1.5 $l/s,m^2$	Sveby Standard
	Heat exchanger efficiency	70%	Yearly mean
	Total Specific Fan Power, SFP	2.0 kW/m^3s^{-1}	BBR18
	Supply air temperature	17 •C	
Office operation	Office hours	Weekdays 8:00-18:00	1 hour lunch break
	Occupant space	20m^2/person	Sveby standard
	Activity level	1 met, 108 W	Sensible and latent heat
	Occupancy factor	0.7	Sveby standard
Lighting	Installed power in office rooms and other spaces	10 and 6 W/m^2	Blomsterberg [13]
	Control	Manual switch on/off	
Computers etc.	Power on/standby	140/10 W/person	Blomsterberg [13]

Flodberg et al 2012

2.2 The parametric study

Different design features were studied in a parametric study and the results were analysed and compared to the base case. The parameters which were analysed were airtightness, insulation levels and thermal mass of the building envelope, glazing and solar control, cooling and ventilation strategies as well as control and installed power of lighting and electric equipment. More details can be seen in [7]. Only existing technology was considered in an attempt to secure cost effectiveness and proven quality.

2.3 The best case solution

The most effective design features, according to the parametric study, were combined as a best case solution and simulated in order to obtain the maximum energy saving potential with existing and cost effective technique. The chosen input are presented in Table 2.

Table 2. Best case data

Parameter	Simulation input
Airtightness	0.3 l/sm^2
Wall U-value	0.1 W/m^2•C
Window U-value	0.9 W/m^2•C
Solar control	External blinds
Heat exchanger efficiency	80%
SFP	1.5 kW/m^{3}s^{-1}
Air flow	Variable (VAV)
Tenant electricity	50 W/person. Off during night
Lighting	8 W/m^2. Daylight dimming and occupancy switch-off

Flodberg et al 2012

2.3 The sensitivity analysis

In a final sensitivity analysis, the reference building was studied regarding aspects which are not likely to be able to influence when designing a building, i.e. the actual building site (climate) and the user related operation of the building.

There are three different climate zones in the Swedish building code [9]. Stockholm (base case) is situated in the north part of the south zone. Other big cities simulated were Malmö in the south part of the south zone, Karlstad in the middle zone, Östersund in the south part of the north zone and Kiruna in the north part of the north zone. Finally, Frankfurt Am Main in Germany was also studied as a reference. Climate data is presented in Table 3.

Table 3. Location and climate

Location	Latitude / Longitude	Temperature Dry-bulb mean •C	Temperature Dry-bulb min /max •C
Kiruna	67.82N / 20.33E	-1.1	-30.2 / 21.0
Östersund	63.18N / 14.50E	3.1	-25.8 / 23.2
Karlstad	59.37N / 13.47E	5.9	-20.6 / 25.1
Stockholm	59.35N / 17.95E	6.5	-18.3 / 26.1
Malmö	55.55N / 13.37E	8.3	-13.9 / 25.0
Frankfurt Am Main	50.05N / 8.60E	10.1	-11.0 / 30.3

Data from ASHRAE fundamentals 2001 and ASHRAE IWEC Weather file 2001 [8]

The impact of the occupants was investigated since this parameter is difficult to predict, and since it affects all heating, cooling and electricity consumption. The base case occupancy factor was set to an average 0.7 during office hours, which is recommended as a Swedish standard [11]. However, a study by Maripuu 2009 [14] argues that 0.7 might be too high compared with reality since different monitoring studies have shown that the actual occupancy factor is closer to 0.5 or even 0.4. Two simulations was performed, one with a low occupancy factor (0.5) and one with the highest possible occupancy factor (1.0). The occupancy rate influences both the number of people and the power for computers and lighting in the simulation model.

3. Results and discussion

In this section, the most important results from the parametric study and the sensitivity analysis are presented and discussed. For more detailed results, see [7].

3.1 Base Case

The total delivered energy for the base case is 139 kWh/m^2,yr including the user related electricity for lighting and equipment (see Figure 3). Excluding these, the delivered energy is 92 kWh/m^2,yr which is below the requirement in BBR18 of 100 kWh/m^2,yr plus addition for large airflows [9]. Hence, the base case achieves the regulation with a small margin. The most dominating posts are heating energy (48 kWh/m^2,yr) and electricity for lighting and equipment (48 kWh/m^{2}yr). Even though internal heat gains from lights and equipment are quite large, and the cooling set-point is strict (23°C), the heating load dominates at this high latitude.

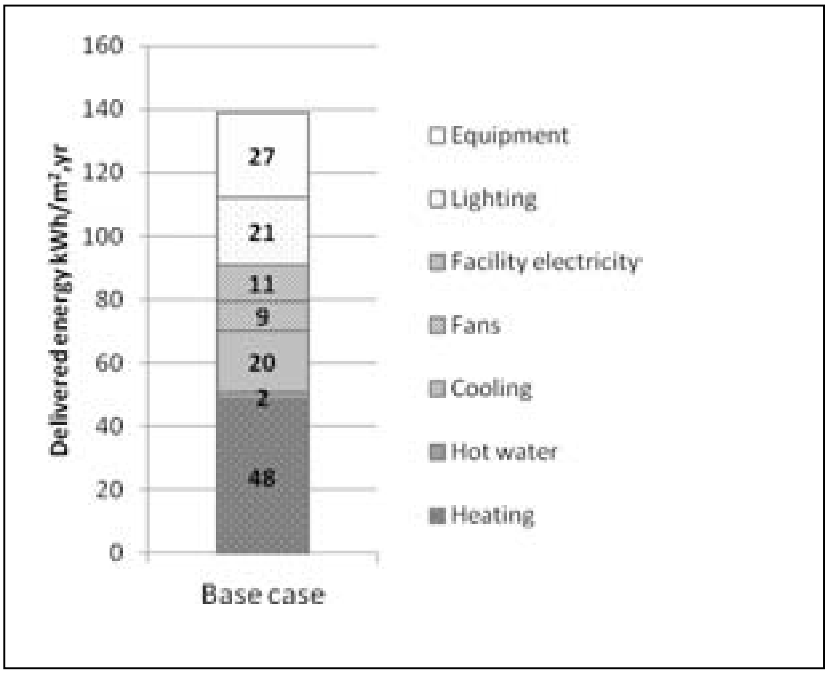


Figure 3. Delivered energy for the base case

3.2 The parametric study

Only the design features with the largest impact on the building's energy use are presented here. Figure 4 shows the parameters with a minimum 5% deviation from the base case in total delivered energy. The most crucial features turned out to be the amount of glazing and demand-controlled ventilation. The least crucial features (<2% deviation) turned out to be building orientation, thermal inertia and cooling with mechanical night ventilation.

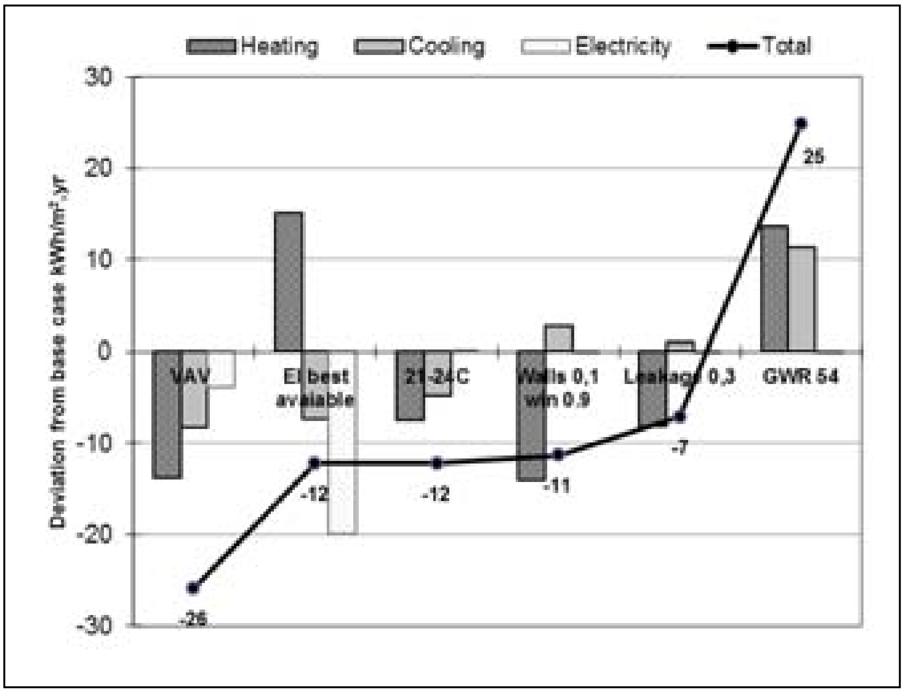


Figure 4. The design features with the largest impact on delivered energy.

Having demand controlled ventilation, with airflows depending on indoor temperature and CO_2 level, instead of having a constant airflow has a great energy saving potential in both heating, cooling and fan energy. Compared to the base case with constant airflow, a total of 26 kWh/m²yr can be saved (heating 28%, cooling 42% and electricity 41%). This result is in line with recommendations from the Passive House Institute, which states that comfort and a good indoor air quality should be ensured and provided by using just the necessary air quantities [15].

An increase in glazing-to-wall ratio, from 31% to 54%, has indisputable great negative effect on the building's energy demand. Heating increases with 14 kWh/ m²yr (28%) and cooling with 11 kWh/m²yr (57%) compared to the base case. Another negative effect with large glazing amounts is the risk of glare. According to a daylight study performed by Dubois [16] on a similar building, the optimal glazing-to-wall ratio in Sweden is 20-40%, with the lower value preferable on the south façade where the risk of glare is higher. Furthermore, Dubois claims that increasing the glazing-to-wall ratio to more than 40% has a negligible effect on available daylight inside the building, and no electric lighting will therefore be saved. Hence, the results presented in this article are supported by Dubois' study, and it can be concluded that the glazing amount shall be kept as small as possible in order to save energy and to avoid glare, but not less than 20% in order to secure enough daylight and view out.

By installing modern low-power office equipment (50W per person) which is completely shut off during night, 9 kWh/m^{2}yr can be saved in user related electricity. By installing low-power lighting fixtures (8W/m^2) and by controlling the lighting system with occupancy switch-off and daylight dimming (>500 lux at desk), the total lighting energy saving potential is 10 kWh/m^{2}yr which is about a 50% reduction of the base case lighting energy. The total saving potential in electricity is 19 kWh/m^{2}yr (29%) and the graph illustrates that even though the heating demand increases with more efficient equipment and reduced internal heat gains, the total energy demand, including cooling energy and electricity, decreases.

Modern Swedish office buildings often have a very strict indoor temperature target at about 22-23•C during working hours. The energy-saving potential when allowing a larger temperature range, for example 21-24•C, is far from negligible. According to this study, 7 kWh/m^{2}yr (14%) heating energy and 5 kWh/m^{2}yr (25%) cooling energy can be saved by accepting a larger range in indoor temperatures. To avoid complains and dissatisfaction, it is important to keep the operative temperature close to the mean air temperature by avoiding, for example, solar radiation impinging on the occupants. It could also be a good idea to inform the workers of the underlying reasons for temperature variations.

Improving the building envelope is one of the first aspects to consider when designing energy efficient buildings. Since the reference building is a multi-storey building, improving the façade has a larger impact than improving the roof and floor. By choosing external walls and windows with U-values corresponding to the Swedish passive house criteria [17], i.e. walls with a U-value of 0.1 and windows with a U-value 0.9 W/m^2•C, the total energy saving potential is 11 kWh/m^{2}yr. The increase in cooling load is compensated by a much higher decrease in heating load. Finally, an improvement in airtightness in the building envelope has a large impact on heating demand as well. This result is not surprising since the base case has a particularly leaky building envelope (1.5 ach or 1.6 l/sm^2 envelope area at 50 Pa). With an airtightness matching the Swedish passive house standard (0.3 l/sm^2 envelope area at 50 Pa) [17], a total 7 kWh/m^{2}yr can be saved.

Other important findings deal with passive design features that are common in many German low-energy office buildings, such as high thermal inertia for heat storage or passive cooling with night ventilation which are not necessarily interesting for other countries. It would probably be more suitable to use the night ventilation strategy in combination with a natural ventilation strategy which does not use any fan electricity. However, a natural ventilation strategy demands a carefully planned building design, based on current conditions in the surroundings, and was therefore not investigated in this study. Furthermore, regarding the result from the thermal inertia study, a heavy building with concrete floors, concrete sandwich walls and various internal walls in concrete has a negligible impact on the heating and cooling loads. This result indicates that the cooling load, due to solar gains and internal heat gains, is not large enough in countries at high latitudes to take advantage of thermal inertia. Another explanation can be the strict temperature range used in Sweden, not allowing as big variations in the indoor air temperature as in Germany and hence activating heating and cooling systems too soon.

3.3 The Best case solution

Figure 5 presents the total delivered energy for the best case solution compared to the base case. The best case solution shows a great improvement in especially heating (26 kWh/m^{2}yr, 54%) and total electricity use (26 kWh/m^{2}yr, 38%), but also in cooling energy (15 kWh/m^{2}yr, 77%). The total saving potential is 67 kWh/m^{2}yr i.e. 48%. The total energy use can probably be further reduced if efforts are made to reduce remaining facility electricity, in particular energy for pumps which in this study is assumed almost 9 kWh/m^{2}yr based on recent office statistics [1].

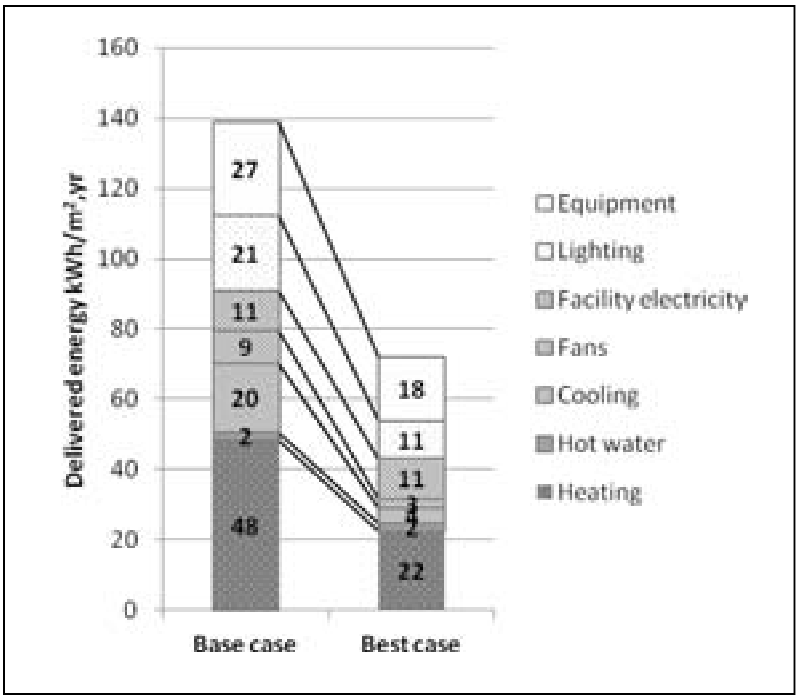


Figure 5. Energy saving potential with the best case solution.

3.6 Impact of climate

Figure 6 illustrates the climate's impact on heating and cooling energy from room units and the air handling unit. The difference in delivered energy between the coldest (Kiruna) and the warmest city (Frankfurt) is 39 kWh/m^{2}yr. Placed in Kiruna, the reference building requires 58 kWh/m^{2}yr more delivered heating energy than in Frankfurt, but placed in Frankfurt it requires 18 kWh/m^{2}yr more cooling energy on the other hand. One interesting result, regarding the Swedish building code, is the fact that the difference between Stockholm and Karlstad only is 3 kWh/m^{2}yr. Nevertheless, the cities represent different climate zones, and office buildings in Karlstad are allowed to use 20 kWh/m^{2}yr more energy than Stockholm [9]. Likewise, Kiruna and Östersund both represent the north climate zone, although the difference in total delivered energy is 24 kWh/m^{2}yr. Furthermore, which is not obvious in the graph, the ventilation cooling battery is hardly used in Kiruna (0.5 kWh/m^{2}yr) while the ventilation heating battery hardly is used in Frankfurt (1.3 kWh/m^{2}yr). This indicates that the supply air temperature of 17•C can be met almost by free cooling and heating in the ambient air combined with the recovered air in the heat exchanger. This indicates the importance of considering the climate when designing efficient HVAC systems.

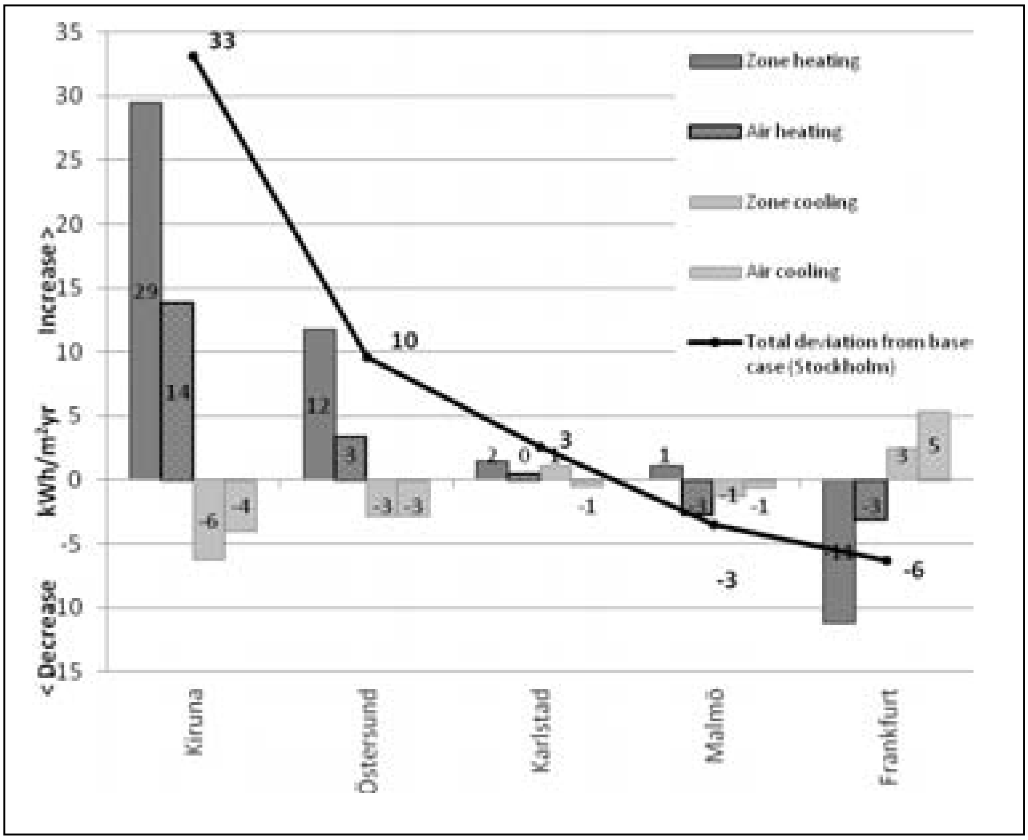


Figure 6. Impact of climate on heating and cooling energy.

3.5 Impact of occupancy rate

The presence of occupants varies over the day and over the year and is difficult to predict. Figure 7 shows what happens with the energy use when the average occupancy rate is low and high compared to the base case (0.7). The heating demand increases when the building is not fully occupied but meanwhile, the cooling energy decreases to some extent. As long as the equipment and the lights are turned off in un-occupied rooms, the electricity decreases as well and the total energy demand is reduced. Hence, if the normal occupancy rate is as low as 0.5 this only has a positive effect on the delivered energy. It is not very area-efficient though. The positive effect might be smaller in landscape office buildings since the lighting is fully on even though the occupancy rate is 0.5.

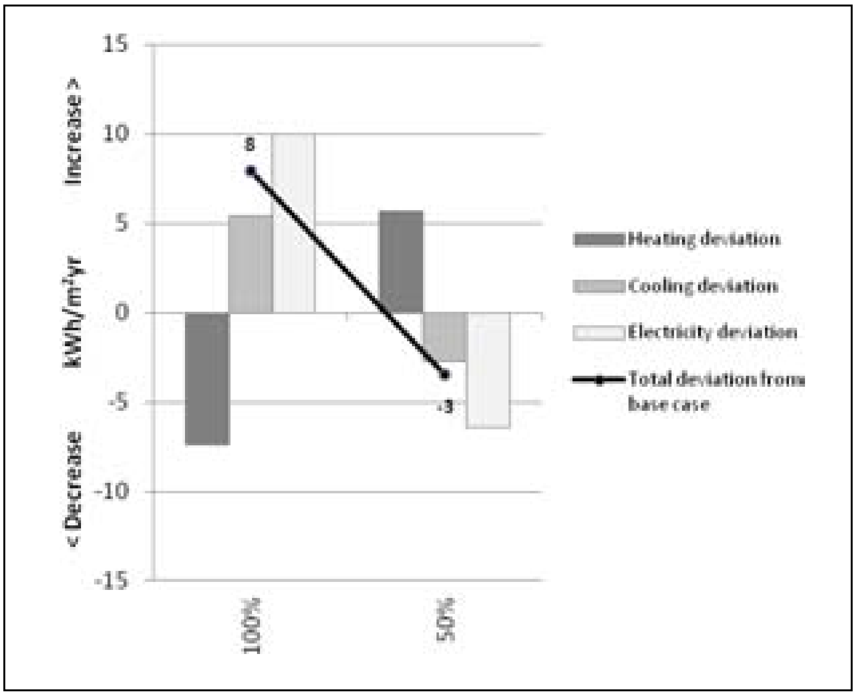


Figure 7. Impact of occupancy rate on delivered energy.

4. Conclusion

Dynamic simulations were carried out with IDA ICE 4 on a typical narrow office building with perimeter cell rooms in Sweden. The most effective design features were combined to see the lowest reachable energy use in the reference building. The simulation result is promising and shows that 48% energy can be saved compared to a new office building designed according to the current Swedish building code, which means that the initial goal of this project was reached. By improving walls and windows, reducing window-to-wall ratios, introducing demand-controlled ventilation and lighting, allowing a larger range in temperature, and by installing more efficient equipment which is completely turned off outside office hours, the heating, cooling and electricity can decrease significantly.

Both the parametric study on energy-efficient equipment and lighting as well as the sensitivity analysis on occupancy rate, indicate that it is crucial to decrease the user related electricity and thus the internal heat gains. A common perception in the building industry is that low-energy buildings suffer when the internal gains are lowered, but this does not apply on office buildings with an active cooling system. This is one of the reasons that tenants' electricity must be regulated in the building code in a soon future. Not only is the user related electricity diminished, but the cooling energy is also reduced and it will be easier to remain a stable operative temperature.

One aim with this study was to completely remove the cooling energy, but this was not fully achieved. This goal might however be possible to achieve if, for example, the air handling system is combined with an earth-to-air heat exchanger for pre-cooling the ambient air during the cooling season, but this has not been evaluated. If other renewable energy sources, such as solar energy and wind power, also are added to this best case scenario, there is a chance that the yearly produced energy will exceed the yearly consumed energy and a net zero-energy building will be produced, but this must be further investigated.

References

[1] Swedish Energy Agency, *Improved energy statistics for non-residential buildings- "Step by step STIL" Report for year 1*, 2007, ER 2007:34 (in Swedish).

[2] Jansson U., *Passive houses in Sweden: Experiences from design and construction phase*, Licentiate Thesis, Lund University, 2008, Report EBD-T--08/9.

[3] Adalberth K., Kamstedt M., *Passive house design as an important path to plus energy house*, Proc. of the 3rd Nordic Passive House Conference, Aalborg, 2010.

[4] Voss K., Löhnert G., Herkel S., Wagner A., Wambsganß M., *Future office building*, TÜV Verlag, 2005 (in German).

[5] Pfafferott J., Herkel S., Kalz D., Zeuschner A., *Comparsion of low-energy office buildings in summer using different thermal comfort criteria*, Energy and Buildings 39, 2007.

[6] Knissel J., *Energy Efficient Office Building with reduced internal heat gains and thermal insulation of passive house standard*, Institut Wohnen und Umwelt D83, 2002 (in German).

[7] Flodberg K., Blomsterberg Å., Dubois M-C. *Future zero-energy office buildings using existing technology: A parametric study of energy use*. Preliminary paper 2012.

[8] EQUA Solutions AB, http://www.equa-solutions.co.uk/ (accessed 2011-12-29)

[9] *Boverket's Building Regulations BBR 18* (BFS 2011:6), http://www.boverket.se/ (accessed 2012-01-17) (in Swedish).

[10] Poirazis H. *Single and double skin glazed buildings – Analysis of Energy Use and Indoor Climate*, Division of Energy and Building Design, Department of Architecture and Built Environment, Lund University, 2008, report EBD-T--08/8.

[11] Levin P., *Input for energy calculations in office buildings*, Sveby (Standardize and verify the energy performance of buildings), 2009, http://www.sveby.org/ (accessed 2012-01-17) (in Swedish).

[12] Building Physics, *HEAT2*, http://www.buildingphysics.com/ (accessed 2011-12-29).

[13] Blomsterberg Å. *Elanvändning kontorsutrustning*. Preliminary report 2011 (in Swedish).

[14] Maripuu M.-L. *Demand controlled ventilation (DCV). Systems in commercial buildings*. Chalmers University of Technology, 2009, No D2009:01.

[15] Passive House Institute, *Quality Approved Passive House Certification – Criteria for Non-Residential Passive House Buildings*, 2011, http://www.passiv.de/ (accessed 2012-01-17).

[16] Dubois M-C., Flodberg K. *Daylight utilization in perimeter office rooms at high latitudes: Investigation of key design features by computer simulations*. Lighting technology and research, 2011.

[17] *FEBY Specification for passive houses*, Version 2009, http://www.energieffektivabyggnader.se/ (accessed 2012-01-17) (in Swedish).

The positive impact of Life Cycle Cost Calculations in the early design phase on energy efficient and sustainable buildings

Martin Pongratz M.O.O.CON GmbH

Gerhard Hofer e7 Energie Markt Analyse GmbH

Abstract:

Currently, Life Cycle Costs (LCC) are not sufficiently considered during the early project's inception phase. On the one hand this is due to the fact that at an early planning stage facility project owners still focus rather on investment than on LCC. On the other hand, existing LCC software is very complex and requires extensive data feeding which, at the early project stage, is not available. Hence LCC calculations are bound to be made at a time when most of the cost driving parameters are already determined, i.e. when architects and engineers are about to close their conceptual work.
This, however, poses a dilemma: Although needed as early as possible in order to provide guidance to the architect's team and in order to positively influence the design concept, the standard LCC results are produced at a moment when it is actually too late for significantly changing the architectural concept...
In this document a new LCC tool is presented which solves this conflict. It indeed allows to obtain LCC results at a very early conceptual stage. Whilst providing a reliable overview of LCC estimates as a whole, the new LCC model can also inform about characteristic key performance indicators such as space efficiency, energy efficiency, cost efficiency (both of the investment and the operations phase) etc. Thus, the tool can be used as an interactive reflection tool that illustrates the impact of particular design options and helps distilling the best possible facility solution that would obtain the most advantageous LCC performance.
M.O.O.CON and E7 have jointly developed such a tool. The tool's concept, structure and functionality had been introduced on a theoretical basis during the IEECB conference in 2010.
In the last two years the tool was used in a wide scope of very different projects.
The paper introduces into the tool's concept and its methodology and explains with examples from case studies the effectiveness and utility of the approach.

1. Introduction

Life-cycle-costs (LCC) are defined as the total cost of a building or of a specific building component throughout its lifetime, including the costs for planning, design, acquisition, operation, maintenance, demolition and disposal less any residual life value. The life-cycle-costs include both investment costs and operational costs throughout the whole functional lifetime, including demolition [1].

Current methods in construction show that in most cases investment cost is still a decisive factor in the construction of a building. However, increasingly it can be seen that the sustainability of a building plays an ever more important role. One of the reasons is the growing demand for buildings with low operating costs coupled with the increasing desire for sustainability evaluation made through sustainable building certification like ÖGNI or DGNB etc.
LCC is included as a specific criterion in both the German Sustainable Building Council's certification [2] as well as in the Austrian certification for a Total Quality Building [3]. In the German certification system a specific methodology to calculate LCC is defined. The calculation of LCC for the building has to be compared to defined benchmarks in order to receive credits in the sustainability certification scheme. In contrast, within the Total Quality Building (TQB) system the auditor has to comply with defined calculation standards and has to include certain types of running costs in order to receive credits in the certification system. Standardization proposals are being developed on the European level by CEN's Technical Committee 350. Workgroup 4 of the committee is working on Standard EN 15643-4 [4] for the assessment of economic performance in the framework of a sustainability assessment. LCC is the main indicator for the economic sustainability.

Considering LCC is important in the early design phase in order to optimize the costs for investment and follow up costs. Usually, various options are taken into account in this phase. A Life Cycle Costs Analysis (LCCA) could evaluate these options: What are the consequences in costs of different insulation standards, different energy carriers or different façade systems? Commonly, a more energy efficient building with higher insulation standards has higher costs for the façade, lower costs for the heating system and, consequently, lower energy costs. External shading systems lead to lower costs for the cooling system and lower energy costs, but to higher costs for investment, cleaning and maintenance of these products. This means, that different design options may have consequences on the investment, energy, maintenance, cleaning and operation costs of a building that should be analysed during the design phase accordingly. In many cases a presumed improvement is just shifting running costs, from energy for instance to maintenance and cleaning costs. A LCCA takes all these costs into account. In this concept the "lowest life cycle cost" option, which is pertaining to the building's entire life cycle, is indeed the most economic one [4].

The impact of LCC plays an important role with regard to the value of real estate. As part of the European project IMMOVALUE [5], research and analysis were conducted on energy efficiency (based on the energy performance certificate), LCC and property value. Findings gathered through interviews [6] showed that sustainable buildings have a higher marketability. At the same time, a clear correlation can be seen between lower operating costs and higher net rent revenues. This illustrates that consideration is given to the inclusion of operation costs in rental costs. International research [7] has shown that sustainable buildings generate higher rent revenues and incur shorter vacancy periods.

These various factors and activities show the growing interest for the methodology of LCC. This method allows for the operating costs of a building to be taken into account at the time of the initial investment. Additional information about future operating costs can already be ascertained during the design phases, thereby creating a better basis of available data for conceiving and planning sustainable buildings.

2. Problem Outline

Figure 1 describes the essential problems of existing LCC approaches. Today it is common that the projected investment and operating costs of buildings are based on benchmarks of existing buildings (e.g. BKI [8], OSCAR [9]). However, "top-down" approaches do not exist in sufficient detail to be used in the early design phases of a building, when different types of building systems with different LCC impact would have to be compared. These approaches are based on categories such as air-conditioned or non-air-conditioned office buildings without paying regard to the particulars of the building design or technical equipment in use in the building. The pooled information remains too general for providing clues as to which particular design solution would be improving or not improving LCC performance. Furthermore, concepts for energy efficient office buildings or those that implement alternative energy systems are not respectively insufficiently taken into consideration. Since all specifications of these benchmark pools consist of building data of the past, they obviously cannot be representative of current potentially feasible sustainable building designs.

Existing software tools for a detailed calculation of LCC (e.g. LEGEP [10], BUBI [11], Baulocc [12], all tools available on the German-language market) are based on the "bottom-up" approach, which makes it necessary to enter itemized data (i.e. lime cement plaster, or type of paint coating/finish of paint). On the one hand this requires a great deal of data entry while on the other hand the data is simply not available at the required level of detail in the inception and early design phases. A quick simulation of different variations, as it is necessary in an iterative design improving process that would be following an integrated design approach, is only possible through a great expenditure of time and effort. In fact, data entering can only start when itemized data would be available which is only during the final technical design phase when all conceptual design issues have already been closed. An iterative procedure though that is forced to take to several rounds of concept finding, design development and technical detailing goes far beyond the scope of any standard planning procedure, normal clients are ready to finance... Therefore, these tools are rarely used as a means for systematic LCC optimization but rather as tool for LCC documentation.

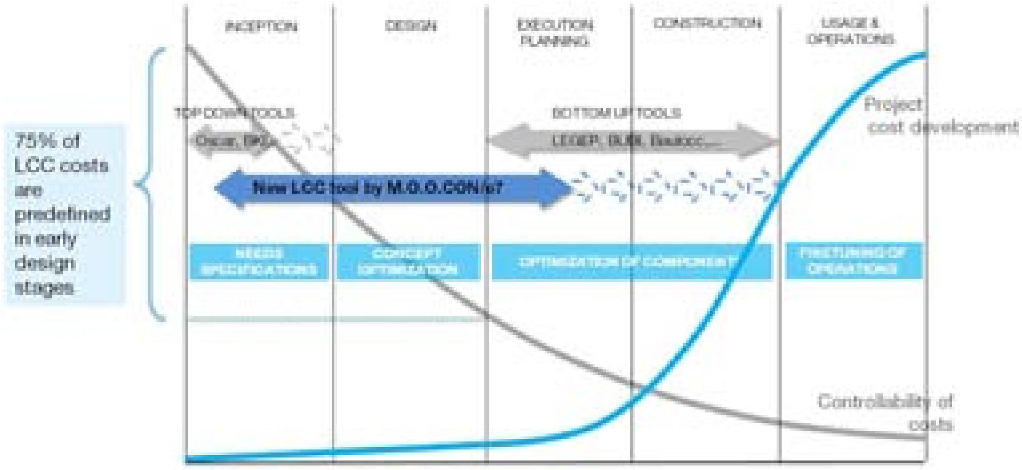


Figure 1: Missing link in models for calculating life cycle costs during the design phase (Source: original illustration)

Likewise, there are countless software programs which calculate economic efficiency or programs for calculating LCC (e.g. LCProfit), that do not come with any cost data pre-sets. Therefore, in order to calculate LCC, the first task is to determine construction and operating costs of the building which again, requires extensive time and effort in the early design phases.
It is exactly in the initial design phase where taking the long-term economical implications into account is most decisive, as the influence of architectural structure and design concepts on LCC results is most significant. Approximately 75% of all investment and operating costs are determined in the initial and early design phases [13]. Further on in the design phase, the execution planning, and the construction phase the influence on cost development declines exponentially. In contrast, the accumulation of the actual building and construction costs increases steadily and irreversibly from execution planning phase on. Therefore, it is of the utmost importance to optimize systems in these first and early phases of a building project. However, just in this period of the project there is a “missing link” in LCC models available. None of the currently available tools allow for a quick and interactive support of the early design process when decisive concepts are born, developed and decided.

3. Research Objectives and Purpose

The objective of the newly developed approach was to model the building in such a way that LCC can already be calculated in the early design phases; even at a point of time when no design for the building is yet available at the definition of requirements.

The main concept is to have an 80/20 Pareto principle that is applied in the design process: by using approximately 20 percent of input efforts 80 percent of the indicators should be calculated. Furthermore, the objective was to develop a tool that would allow first LCC calculations being carried out before even a first architectural concept is drawn.

The purpose of this LCC model is to provide reliable LCC data for allowing both project owners and architects to take resilient and informed decisions on how to develop building designs that would be following an optimized LCC profile. The tool would have to

- inform about the LCC estimates in all early stages of the inception and design phase
- inform both about the qualitative aspects and the performance aspects a given concept would be delivering (in order to be able to weigh pros and cons of additional investment into potential quality gains)
- help assess and analyze how a given concept could be improved in its LCC performance
- provide fairly quick evaluation results on various design options that would be resulting of the first analysis

By integrating the necessary input data for this model into a software tool, it should be possible – with an acceptable expenditure of time and effort – to make reliable statements on prospective investment and operating costs of the building and thereby accelerate the realization of sustainable and energy efficient construction concepts.

4. Methodical approach

Figure 2 shows the different phases of a design process. During the inception phase the actual needs and requirements are defined. For instance which total area would be needed, what would be specific functions the building would have to service, which functional aspects would have priority, what fit-out qualities would be expected? When the requirements are defined, the architect designs the first concepts. In this phase the life cycle costs of the general building concept should be optimised. Later on in the design phase LCC of building components will be analysed and finetuned.

In order to make use of this approach, models for generating the space allocation program and volume program for the building as well as data for construction costs and operating costs are necessary on an aggregated level. This enables data entries to be made even before the beginning of design work itself. In addition, an energy calculation model should illustrate the interdependency between the building design, the façade, and the building equipment system. If this is executed in this way, no additional calculation tool is needed. The model design should enable LCC analysis during the design phase for optimisation of the building concept and, to a lesser extent, during the preparation for construction for the optimization of the building components.

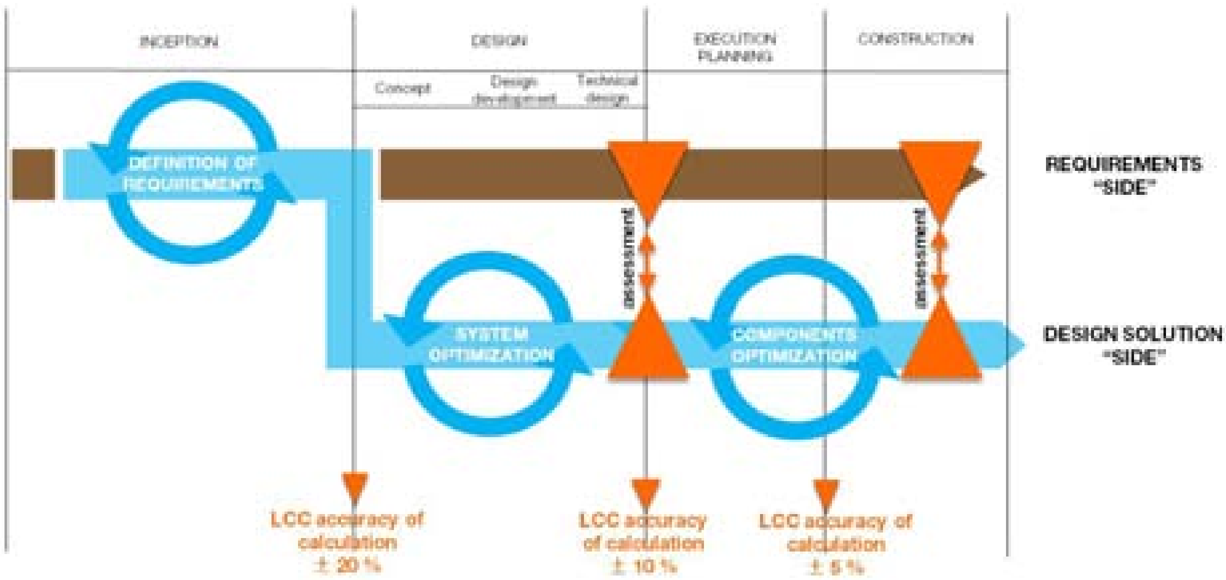


Figure 2: Areas of application of the LCC tool from initiation through to the detailed design phase (Source: original illustration; spread of accuracy was determined by the ex-post analysis of 15 accomplished projects, comparing the project forecast that was computed at a given moment in the project process with the final project cost determined at project closure)

5. Realisation of a new LCC model

5.1 Reducing input data

On the one hand there should be as little data input as in a top-down approach; on the other hand the results should provide building specific information and clues as a bottom-up methodology would provide. In order to combine the advantage of the fast cost estimation of the top-down method with the advantage of the accuracy of the bottom-up method it was necessary to adopt a new approach.

At the same time, the decision-making process in the design phase was incorporated into the model with great detail. Figure 3 describes the decision making process in a building project. At the bottom there are the stages of life, beginning from acquisition to operation and disposal of the building. On the vertical axis there are the different levels of detail in the decision process. Furthermore, different parts of the building such as structure, envelope, services and finishes are mentioned separately. In general, decisions are made mainly at the strategic phase and system levels during the stage before the construction of a building as shown in figure 3.

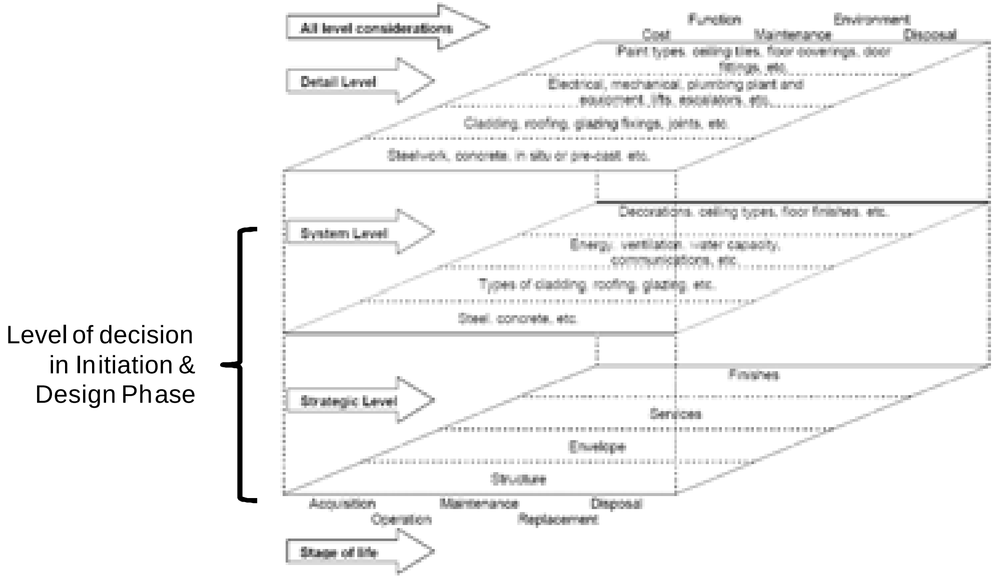


Figure 3: Levels in the decision-making process (Source: European Commission [14])

Based on cost analysis, building For this reason, the building was divided into aggregated building elements with the aim of reducing input data. These elements were evaluated regarding the influence on costs and their share in the total amount of the building cost. Moreover, the relevance with regard to system decisions in the early design phase was taken into account.

Regarding the building, the impact of the various usage areas on cost was investigated with a main focus on those areas that would ensure the main designated purpose of the facility (f.ex. office areas in an office building; bedrooms in a hotel etc.) and an outline of specific “special areas” (e.g. conference centres, canteen etc.). The primary utilization of an office building, as the names suggest, is for office and administrative use. The main usage spaces are complemented by decentralized spaces such as staircases, elevators, restrooms, as well as centralized special usage areas such as conference rooms, the lobby, cafeteria(s), storage areas or carports. The essential system decisions are, by definition, directly related to the main usage and the areas that support the main usage. Being quantitatively the major part of the building these main usage areas also have a major impact on overall costs. Consequently, the building elements for the main usage areas (e.g. areas for “office” spaces) need to be provided at a different level of detail than for the special usage areas which are but ancillary areas.

elements were defined at different levels of detail. Depending on what a particular area would be used for, the aggregation of the building elements was carried out at a different level. For the main usage area, “office”, cost relevant issues are compiled at a more detailed level of constructional elements (as defined by Austrian Standard ÖNÖRM B 1801-1 [15]). For less cost relevant issues or design elements with regard to less cost relevant usage areas cost relevant issues were compiled at the more general level of cost ranges (as defined by ÖNORM B 1801-1 [15]).

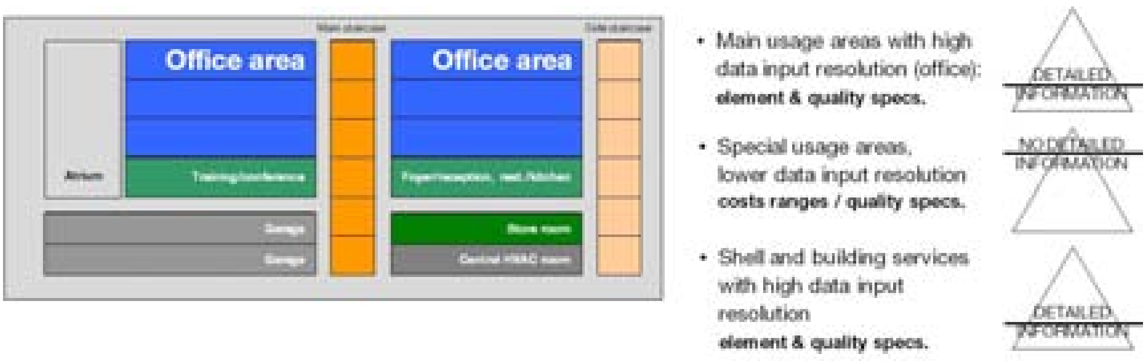


Figure 4: Structure of costs for the main usage “office” space and special usage space (Source: original illustration)

For all the relevant cost drivers the building elements were consequently compiled from bottom-up aggregated items. Referring to figure 4 the level of detail for building elements are the system level. For less relevant costs ranges and usages they were bottom-up aggregated in a less detailed level and tested against top-down benchmarks, hence a certain imprecision can be tolerated due to the lower relevance of the data. For this cost data the level of detail is the strategic level. Thus the number of elements and consequently the amount of data entry is reduced significantly.

5.2 Virtual building model

For the modelling of the building, a virtual building model was developed. This building model is based on the experience the company M.O.O.CON acquired as a result of a very large number of office building projects that allowed M.O.O.CON to draft general building typologies and structural standards that help for the setting up the model [24; 25]. Based on the requirements of the client’s brief, the virtual building model can calculate the approximate volume and surface area of the building at a time where no design drafts for the building have been put forward. Aside from the calculation of volume and surface area this tool can also optimize usable floor space. Optimising the use of floor space is a powerful lever for the reduction of construction and operating costs. Through the reduction of conditioned volume, energy costs can also be reduced.
In this process office spaces and other special spaces in the building are combined in different design variations to floors and building cores. Subsequently, the gross floor space is calculated. Thus, it is possible to optimize the floor space even at this point of time, which in turn leads to lower follow-up costs. Figure 5 shows the model for optimising the floor space: the columns of the table contain the number of office areas adjacent to one staircase, the rows describe the total number of staircases in the building. The letters “HH” define high rise buildings; “FB” means low rise buildings. The numbers in the coloured cells are the total area of the building. By using this model, the type of building with lowest area can be chosen.

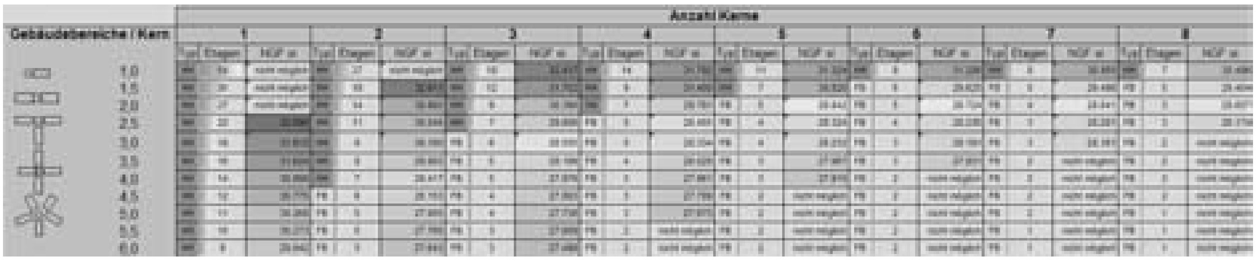


Figure 5: Output of floor space values per building sector and number of cores. (Source: M.O.O.CON)

With the introduction of an architectural concept, the data in the building volume model is changed in accordance with the significant geometrical dimensions (essential building area data, façade, building orientation). With minimal additional effort for data entry the existing data can be optimally used.

5.3 Cost database

For the calculation of LCC in early design phase it is essential to have a cost database for investment and running costs in order to be able to calculate LCC very quickly. Therefore, based on the defined building elements and different quality levels of decentralized spaces, the costs for more than 1,200 database elements were calculated. Different sources were incorporated for an estimation of the investment and operation cost. These figures were integrated into a database which was specifically developed for this model.

In order to determine the total cost of the elements comprehensive building data was necessary. This was ascertained by drawing on the virtual building model or the architectural concept. As with the aggregation of the building elements, it was also necessary to keep the amount of required data to a minimum for the calculation of comprehensive building data.

Again, the results of the analysis of the cost drivers were drawn to and an attempt to incorporate only a few significant parameters from the building design was made. All other data should be calculated by algorithms based on these entries. The algorithms were derived from design regulations for office buildings, fire safety regulations, work space regulations and years of experience of various projects of M.O.O.CON. The significant parameters for the efficient use of space such as width and structure of building could easily be entered and changed. The data entry was done through a space allocation and function program in the initiation phase. Common measurements of architectural plans provided at this time were used as a basis during the early design phases.

Building elements could be defined and associated with investment and operating costs based on the structure of the usage area as well as significant system decisions, which contributed to the comfort of the interior (acoustics, visual comfort). For a usage area such as a cafeteria, this meant the definition of different building elements for different standards at a level of cost ranges (such as "high quality cafeteria"). For the office areas building elements for flooring, floor construction, office partitions, hallway dividing walls, noise insulation, etc. were defined (e.g. office area, flooring, carpet, high quality carpet). For the building itself, building elements such as façade, HVAC and many more had to be defined.

5.4 Calculation of energy use and energy costs

Founded on the building model of selected building elements and user specified comfort guidelines, it was now possible to calculate energy consumption based on the calculation for the energy certificate complemented by several significant factors such as the influence of thermal mass, different usage areas, the consideration of daylight, the actual energy consumption of different utilities like lighting, cooling, heating and ventilation.

The energy calculation was divided into different degrees of detail. For the main use of the building the energy consumption was calculated according to an energy balance model by using ISO 13790 [16]. Precisely, the Austrian standards for calculating the energy performance certificate were used (ÖNORM B 8110-6 [17], ÖNORM H 5056 [18], ÖNORM H 5057 [19], ÖNORM H 5058 [20]). For detailed calculation of energy demand for lighting the European standard ÖNORM EN 15193 [21] was incorporated taking the use of daylight into account. To be more precise, additional aspects in comparison to the energy performance certificate were included in order to calculate the energy consumption. The thermal mass was calculated based on a detailed assessment of the respective building elements. The operation time of the building could be inserted individually.

The decentralised areas were calculated very roughly. In these areas the usage of space is normally most important for the energy use (e.g. in the kitchen the internal appliances are more important for the energy use than the system of the façade). In these areas the heating and cooling level is depending on the energy balance of the main usage area. Furthermore, energy demand details based on data of DIN 18599-10 [22] and SIA 2024 [23] were integrated without calculation of an energy balance.

Based on the integration of a detailed energy assessment method and by using an individual operation period as well as comfort date, realistic energy usage scenarios could be compiled. Results of the calculation were compared to the general benchmarks of the OSCAR report [9]. Owing to the programming of a software interface the entry of the building model and of the building elements could be directly linked to the energy cost calculation, making any additional step unnecessary. The linking of the building elements to the use of energy calculation allows for an additional correlation between building design and heating and cooling load of the building's central equipment system. Heating and cooling loads are calculated through the entry of the building's volume and façade design. These loads are indicators for the selection of the dimension of the building equipment systems for heating and cooling. An improved insulation of the façade contributes directly to lower investment and operating costs of the building equipment systems. The chosen method of calculating the energy costs also allows for the selection of alternative energy systems such as heat pumps, photo-voltaic and thermal solar systems.

Based on investment and operating costs provided by a per-element basis (originating from the building elements) as well as building specific calculated energy costs it is now possible to calculate LCC using the net present value method or the method of complete financial plans.

By changing significant parameters (inflation, construction cost index, energy cost index, depreciation period and financing options, etc.) their effect can be simulated. Sensitivity analyses can be done by changing the entered value for calculations. Cost parameter of the building can be varied in Excel allowing for a risk analysis of individual parameters to be carried out.

6. Discussion of methodology

In the test phase of this LCC model investment cost and operating cost data, derived from completed and operating buildings, were compared with corresponding results generated by this model. Through this data it was possible to test the programmed algorithms and the cost estimates and make any necessary change. Having completed the testing phase, it was possible to confirm that the chosen approach leads to extremely short data entry times. There are around 50 data inputs needed for the building geometry and around another 50 for the quality of the building elements. At the same time the cost reliability achievable in this early design phase remained within the margins of +/- 10 to +/- 20% for all simulated projects. Thus, it could be shown that with sufficient knowledge of significant cost drivers the simulation effort can be minimised without compromising on data reliability.

However, this cost data and results of LCC are just limited to a national level. In the test phase buildings from Austria and Germany were calculated. For this region, by taking certain regional factors for costs into account, this model can be applied by using the developed cost data base.
Furthermore, there are restrictions in the building types. At the beginning, this model was developed just for office buildings. Now, the building types were extended to nursing homes, hospitals, hotels and schools. In general, these building types that have regular and standardized rooms in the main usage spaces can be used.

The cost data was mainly developed together with big Austrian building and HVAC companies. These companies have their focus on big non-residential buildings. Therefore, data cannot be used for small buildings less than 1,000 square meters are and for residential buildings.

7. Examples for LCC calculations

The focus of the application is on the early design phase of a building project. Here, the LCC tool is used for the following purposes:

- Optimization of life cycle costs in the project initiation and determination of a reference value for life-cycle costs for the planned space and functional program, considering sustainability goals.
- Comparison of life cycle costs of different building designs in the context of an architectural competition
- Optimization of life cycle costs by comparing different solution in the preliminary design and design of a building project

7.1 Assessment in the architectural competition

A public project developer plans a nursing home with high sustainability standards. According to comprehensive sustainability criteria and the LCC tool, prior to the analysis of the actual design concepts delivered by the competing architect teams of the competition, an abstract virtual building model can be established as a reference building providing reference values.
With the help of cost estimates delivered by the competing architects and the individual LCC modelling of each architectural concept allow to generate for each design concept an individual LCC estimate. These results can be compared with the reference value. The deltas of each LCC category from the reference value, if significant, bear valuable information about the project's LCC profile. Summed up in a report this information provides the architectural Jury with valid comments on the concepts propensities with regard to LCC qualities. Each project can be commented in the sense that it either tends to underperform or outperform the values set by the virtual reference model.
Hence, the Jury is provided with consistent comments on the basic propensity of a concept with regard to LCC performance. As a result, the Jury is enabled to include LCC considerations into its assessment and evaluation procedures.

Figure 6 shows the investment costs of the five submitted projects and the reference value for the investment costs divided into costs for structural, HVAC and finishing works. Figure 7 contains life cycle costs in a 25 years reference period while figure 8 shows the accumulation of life cycle costs up to a time period of 60 years.

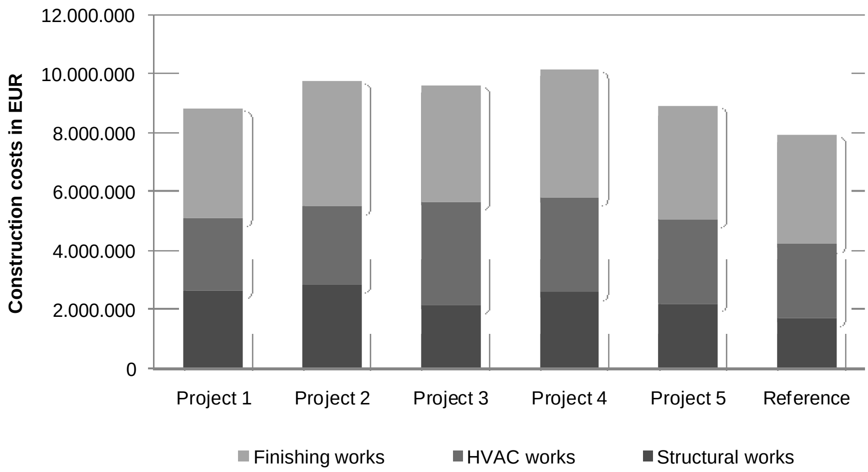


Figure 6: Construction costs in EUR of five projects in the architectural competition in comparison with the reference value (Source: original illustration)

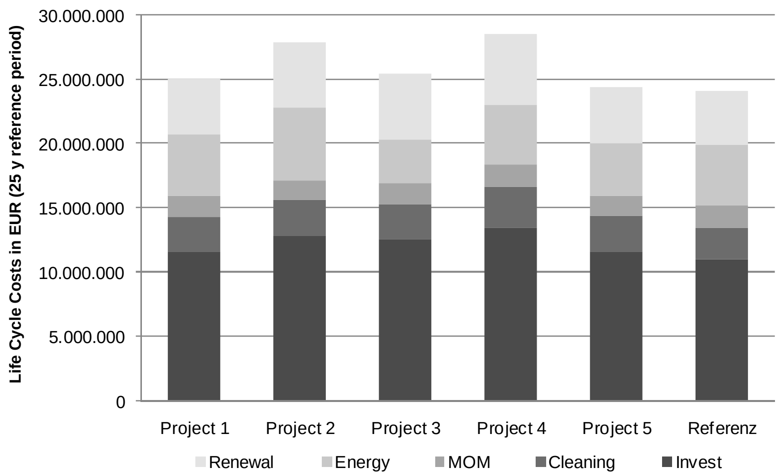


Figure 7: Life cycle costs in EUR of five projects in the architectural competition in comparison with the reference value in 25 years reference period (Source: original illustration)

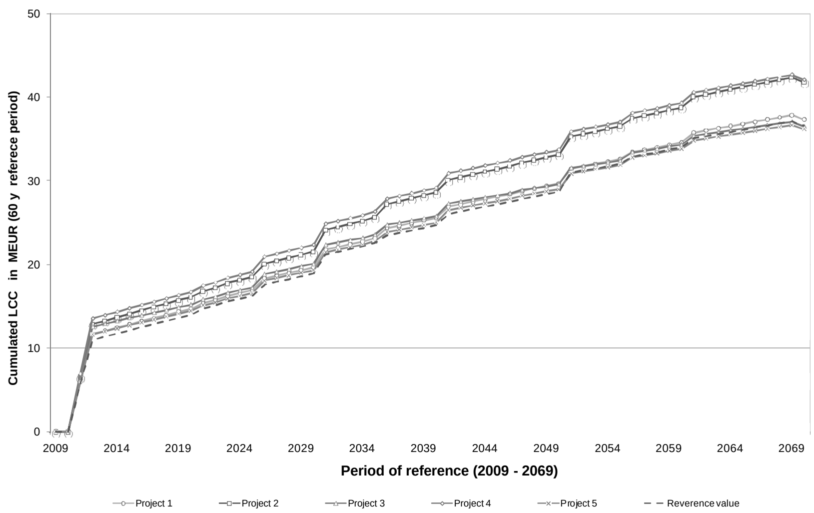


Figure 8: Accumulation of life cycle costs in millions of EUR of five projects in the architectural competition in comparison with the reference value in 60 years reference period (Source: original illustration)

Comparing all projects, there are two projects (No. 2 and 4) that obtain clearly higher LCC than other projects and the reference value. Also, project 3 for example clearly outperforms the reference value by about 30% as far as the energy consumption is concerned.
By using these graphs and cost value data, the projects can be assessed in their economical longterm effects. The data is not sharp enough to provide absolute forecasts. But the methodology and the tool allows a clear indication of propensities whether concepts tend to be economical or not economical from a LCC perspective.

7.2 Assessment in the preliminary design phase of an office building

A private project developer plans a new office building in passive house standard. For this project approximately 3% of additional investment costs for a passive house were weighed against the anticipated life cycle operating costs. It could be shown that the additional investment costs could be refinanced within 17 years (assuming an energy cost index of 5%).

For a speculative real estate development breakeven considerations are very important. Also, it is useful to be able to demonstrate to future tenants that future operation cost would contribute to savings. Exemplary full costing calculations of the life cycle cost can illustrate these points.
Only if full costing cost calculations demonstrate that energy efficient buildings -even if more expensive in investment- break even in reasonable time in comparison with less investment intensive low energy efficient buildings, investors will be persuaded to invest into the more energy performing but more expensive buildings.
For such decision making reliable cost calculations models are required. The LCC tool can be such a model.

For the project mentioned above, the LCC tool helped to identify the cost drivers that over the life cycle would inflate LCC. As this procedure was done in the early design phase architects were given the opportunity to rethink their concepts very early in the planning process so that the designers could focus their creative thoughts on optimising on the most cost relevant and cost driving elements.

For example, a thorough comparison between different energy sources such as gas, district heating or geothermal energy was carried out; additionally the use of photovoltaic and thermal solar plant was considered. Also the combination of elements and system decisions could be discussed with the help of the LCC tool and every conceptual idea could be doublechecked as to its impact on LCC. Then the solution with a particular good investment/LCC effect ratio was retained (use of geothermal energy in combination with an activation of thermal mass (peak load) and district heating).

8. Conclusion

The development of a new model for calculating LCC in the early design phase was successfully transferred to the market. There are first projects in the demand planning phase, for architectural competition as well as in the design phase of a building. The results of this model are mainly used to give the construction client valuable information about the future cost of the building.

At the moment this model is extended to the refurbishment of buildings. The main aim is to compare different solutions (refurbishment of an existing buildings, construction of a new building) in the initiation phase of a building in order to give the construction client valuable decision making information for the optimal economical solution.

In general, the economical dimension of a building is just one aspect. By advising the construction client in the early design phase all aspects of sustainable building are taken into account. Potential negative and positive aspects of different design solutions are mentioned in order to find the best integrated design solution for the building.

9. Acknowledgement

The development of the mentioned model for early calculation of LCC in the design process was funded by the "*ZIT - Die Technologieagentur der Stadt Wien*" (Agency for Technologie of the City of Vienna). The

further development of an LCC model for the refurbishment of buildings is supported by the Austrian programme "*Haus der Zukunft plus*" (Building of the Future plus) within the project BIGMODERN.

The development of a database for investment and running costs of building elements was supported by the Austrian construction company *Allgemeine Baugesellschaft - A. Porr Aktiengesellschaft* as well as the Austrian and international building equipment supplier *Cofely Gebäudetechnik GmbH* and the engineering practice *Allplan GmbH*.

10. References

[1] Hofer, Gerhard: Integrated Planning for Building Refurbishment - Taking Life-Cycle Costs into Account (LCC-Reburb), final report, project in the framework of the European Commission´s Energy Efficiency Programme SAVE, Vienna, 2006.

[2] Deutsche Gesellschaft für Nachhaltiges Bauen e.V., Deutsches Gütesiegel für Nachhaltiges Bauen, Aufbau – Anwendung – Kriterien. Issue 3/2009. Stuttgart, 2009.

[3] Lechner, Robert: TOTAL QUALITY BAUEN: Ergänzung und Erweiterung des bestehenden Gebäudebewertungssystems, Wien, 2009.

[4] prEN 15643-4:2009-12-31 (working draft): Sustainability of construction works — Sustainability assessment of buildings — Part 4: Framework for the assessment of economic performance, Brussels, 2009.

[5] IMMOVALUE: Improving the market impact of energy certification by introducing energy efficiency and life-cycle costs into property valuation practice, IEE/07/553, 2010, www.immovalue.org.

[6] Bienert, Sven et al.: Integration of energy efficiency and LCC into property valuation practice, paper for the 15th PRRES Conference, January 2009, Sydney. Download at www.immovalue.org.

[7] Fuerst, Franz; McAllister, Patrick: Green Noise or Green Value, Measuring the Price Effects of Environmental Certification in Commercial Buildings, Reading, 2008.

[8] Baukosteninformationszentrum Deutscher Architekten (BKI): Statistische Kostenkennwerte für Gebäude, 2010, www.baukosten.de.

[9] John Lang Lassalle: Büronebenkostenanalyse OSCAR 2008, Berlin, 2009. Can be ordered from www.joneslanglasalle.de

[10] LEGEP Software GmbH: LEGEP Bausoftware, bauen berechnen betreiben; Ein Werkzeug für die integrierte Lebenszyklusanalyse, 2010, www.legep.de.

[11] Riegel, Gert Wolfgang: Ein softwaregestütztes Berechnungsverfahren zur Prognose und Beurteilung der Nutzungskosten von Bürogebäuden, Darmstadt, 2004.

[12] Herzog, Kati: Life Cycle Costvon Baukonstruktionen – Entwickl. eines Modells u. einer Softwarekomponenten zur ökonomische Analyse und Nachhaltigkeitsbeurteilung von Gebäuden, Darmstadt, 2005.

[13] Statsbyggs: LCProfit, 2010, www.lcprofit.com.

[14] European Comission, DG Enterprise and Industry: Task Group 4: Life Cycle Costs in Construction, Brussels, 2003.

[15] ÖNORM B 1801-1:2009 06 01: Bauprojekt- und Objektmanagement - Teil 1: Objekterrichtung, Wien, 2009

[16] ISO 13790:2008 03: Energy performance of buildings - Calculation of energy use for space heating and cooling, Genf, 2008. Can be ordered from www.iso.org

[17] ÖNORM B 8110-6:2010 01 01: Wärmeschutz im Hochbau - Teil 6: Grundlagen und Nachweisverfahren - Heizwärmebedarf und Kühlbedarf, Wien, 2010

[18] ÖNORM H 5056:2010 01 01: Gesamtenergieeffizienz von Gebäuden - Heiztechnik-Energiebedarf, Wien, 2010

[19] ÖNORM H 5057:2010 01 01: Gesamtenergieeffizienz von Gebäuden - Raumlufttechnik-Energiebedarf für Wohn- und Nichtwohngebäuden, Wien, 2010

[20] ÖNORM H 5058:2010 01 01: Gesamtenergieeffizienz von Gebäuden - Kühltechnik-Energiebedarf, Wien, 2010

[21] ÖNORM EN 15193:2008 01 01: Energetische Bewertung von Gebäuden - Energetische Anforderungen an die Beleuchtung, Wien, 2008

[22] DIN 18599 10:2007 02: Energetische Bewertung von Gebäuden – Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung – Teil 10: Nutzungsrandbedingungen, Klimadaten. Berlin, 2007.

[23] SIA Merkblatt 2024: Standard Nutzungsbedingungen für die Energie- und Gebäudetechnik, Schweizer Ingenieur- und Architektenverein. Zürich, 2006

[24] Pongratz, Martin: The Fractal Organisation of Factory and Office Work and its Consequences for the Company and the Individual. In: Human Factors in Organisational Design and Management IV, Elsevier Science B.V., Amsterdam, 1994, 17-22.

[25] Pongratz, Martin: “Planning from inside out: a comprehensive way of dealing with both complexity and high quality standards in office buildings”; Sixth International Symposium on Human Factors in Organisational Design and Management, The Hague, The Netherlands, 19-22 August 1998, Elsevier

European Commission
EUR 25759 – Joint Research Centre – Institute for Energy and Transport

Title: Proceedings of the 7th International Conference on Energy Efficiency in Commercial Buildings
IEECB 12

Authors: Paolo Bertoldi, Gueorgui Trenev

Luxembourg: Publications Office of the European Union

2013 – 711 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print)

ISBN 978-92-79-28222-5 (pdf)
ISBN 978-92-79-28223-2 (print)

doi: 10.2790/77021

Abstract: This book contains the proceedings of the seventh International Conference on Energy Efficiency in Commercial Buildings Frankfurt, Germany 18 - 19 April 2012

LD-NA-25759-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

Publications Office

ISBN 978-92-79-28222-5