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Abstract

This book contains the proceedings of the 8th International Conference on Energy Efficiency in Commercial Buildings which took place in Frankfurt, Germany 1-3 April 2014.
The IEECB conference brings together all the key players from this sector, including commercial buildings' investors and property managers, energy efficiency experts and building technologies researchers, equipment manufacturers, service providers (ESCOs, utilities, facilities management companies) and policy makers, with a view to exchange information, to learn from each other and to network.
The wide scope of topics covered during the IEECB'14 conference includes: smart building and low energy buildings, (Nearly) Net Zero Energy Buildings, equipment and systems (lighting, HVAC auxiliary equipment, ICT & office equipment, miscellaneous equipment, BEMS, electricity on-site production, renewable energies, etc.) and the latest advances in energy efficiency programmes, regulation & policies for public and private sector commercial buildings.
Potential readers who may benefit from this book include researchers, engineers, policymakers, energy agencies, electric utilities, and all those who can influence the design, selection, application, and operation of electrical motor driven systems.

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Bridging the gap between operational and asset ratings – the UK experience and the green deal tool

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Abstract

To truly understand how a building uses energy you require both an Asset and an Operational energy rating. An asset rating models the theoretical, as designed, energy efficiency of a particular building. 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.

There is significant confusion in the UK non-domestic property market between the two different building energy ratings currently in use.

In the UK Green Deal (GD) tool was designed by BRE's Building Energy Modelling team, using the current interface to the Simple Building Energy Model (iSBEM).

iSBEM previously captured all the details of the building (geometry, constructions and building services) in a series of zones. This data was then used to produce an asset rating for the purposes of showing compliance to Approved Document Part L of the UK's building regulations and to produce an Energy Performance Certificate (EPC).

The iSBEM software has been further developed, in that further functionality has been added so that it captures and quantifies the degree of Energy Management; along with the meter readings and actual hours of occupancy.

This paper discusses the underlying principles of how the GD tool was 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 modelling 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. The 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 (Figure 1) to which energy efficiency is a major contributor.

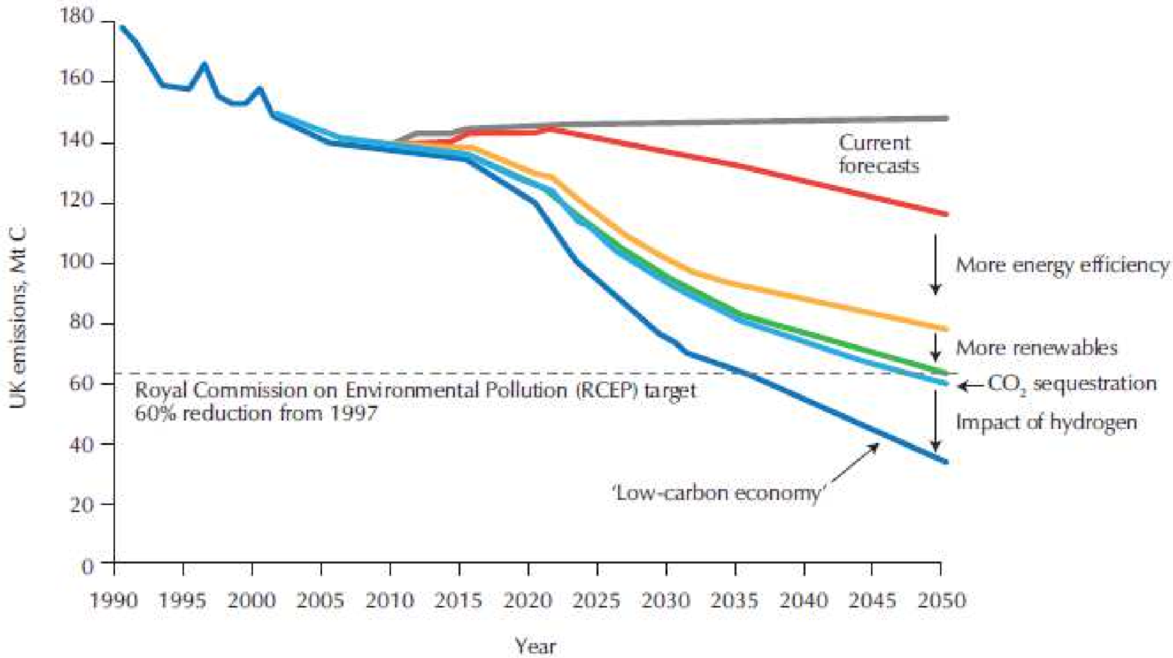

Figure 1: UK government carbon reduction targets [7].

This all indicates the need for energy management as highlighted in a recent review of best practice [**8**]. 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 UK 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. 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 potential of the building itself (the fabric) and its services (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 behaviour also create emissions, which are reflected in the operational rating.

Two offices 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 could indicate that it is used badly. In the latter, it is likely measures to change the behaviour of the end users will be the best option for reducing energy use and carbon emissions. However, because the majority of operation ratings use standard conditions of occupancy density and hours; this also needs to be investigated.

An example of an asset rating is the EPC produced for buildings in the UK. One of the software tools used to create a Non-Domestic EPC (NDEPC) 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 [9]. A NDEPC can be generated using the tool iSBEM, the free downloadable user interface for SBEM (http://www.ncm.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.

The iSBEM software is also used for demonstrating compliance with the UK Building Regulations for buildings other than dwellings by calculating the annual energy use for a proposed building and comparing it with the energy use of a comparable 'notional' building.

Building Regulations Approved Document Part L2A [10] uses a holistic approach where a building must achieve a better predicted performance than a Target CO_2 Emission Rate (TER), which is calculated at both the design and as built stage by tools such as the Simplified Building Energy Model (SBEM). L2A contains limiting fabric parameters and uses the standards laid out in the Non-Domestic Building Services Compliance Guide (NDBSCG) [11] as design limits (or backstop values).

An example of an operational rating is a 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 and to produce the DEC and an advisory report (https://www.gov.uk/government/publications/display-energy-certificate-software-specification).

BRE's Building Energy Modelling team identified a possible solution to the problem of linking the two rating methods, which has been rolled out as an Audit tool in Mauritius. The Mauritian Building Energy Audit Tool (MBEAT) tool is able to join the two ratings together for the purpose of an Energy Audit. This tool was a pre-cursor in that it was simplified by the fact that only cooling needed to be considered which was satisfied by a single fuel type – electricity.

Using the lessons learnt from the production of MBEAT, members of the team developed the Green Deal (GD) assessment tool for non-domestic buildings for the Department for Energy and Climate Change (DECC). The tool supporting this – the non-domestic GD tool is based on iSBEM and has the ability to link NDEPCs and DECs. https://www.ncm-sbem.org.uk/.

The Mauritian Building Energy Audit Tool (MBEAT)

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. MBEAT consists of a calculation methodology (described in the sections below), 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

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 iSBEM:

a Enter general information about the building, the owner, and the energy auditor, select the appropriate weather data and building type.

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.

The building services systems, zones, envelope elements, windows, and doors are all referred to as "**building objects**" in iSBEM. Each of these building objects is linked together so that iSBEM can calculate the energy consumption of the building. It should be noted that at this point SBEM sets all the management scores of the building as being 'well managed'.

iSBEM 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. iSBEM 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. This requires information from the following sources shown in Table 1:

Information	Source
Building geometry such as areas, orientation, etc.	Energy auditor reads from drawings or direct measurement.
Weather data	Internal database.
Selection of occupancy profiles for activity areas	For consistency, these come from an internal Activity Database – energy auditor selects by choosing building type and activity from the database for each zone.
Activity assigned to each space	Energy auditor defines within iSBEM by selecting from internal database (the user should identify suitable zones for the analysis by examining the building or drawings).

Building envelope constructions	Energy auditor selects from internal Construction and Glazing databases or inputs parameters directly. Energy auditor can also define their own constructions in the user-defined construction database.
HVAC systems	Energy auditor selects from internal databases or inputs parameters directly.
Lighting	Energy auditor selects from internal databases or inputs parameters directly.

Table 1: Calculation parameters for iSBEM

Defining a poorly managed asset

MBEAT and the GD tool compare and adjust 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.

Adjustment to asset parameters to account for poor management

Some management issues can be simulated by changes to asset parameters, in particular poor maintenance, see Table 2.

Issue	**Simulate by**	**How much for poor management?**
Cooling generator poor maintenance	Degraded SEER	-0.5? -1.0?
Air filters not cleaned, ductwork not cleaned	Increased SFP; ensure leakage testing not selected	+0.5? +1.0?
Luminaires not cleaned (although perhaps lighting would just underperform rather than require more energy)	Reduced efficacy lumens/watt	-25% (would have to express as wattage change)
Inadequate lamp replacement policy	No change – just underperforms	
Poor management of hot water systems	Increase heat losses and untick time control of pump	50% increased loss over default?
Poor central controls	Do not have optimum start/stop, weather compensation etc (although these don't affect cooling energy anyway)	None
Lack of management supervision	Do not select M&T etc	None
Poor localisation of time, temperature controls	Apply activity with longest duration, lowest cooling set points, most ventilation to whole building	Need to be careful that this is not accidentally beneficial to some other aspect of energy consumption
Poor localisation of lighting control, lack of tailoring lighting levels to different activities	Apply activity with highest lighting lux level to whole building; untick local manual switching	Should tend to give higher cooling energy as well
Lack of daylight and occupancy controls	Do not select any of these controls	
Lack of weather tightness	Debatable whether to adjust air permeability as this may be beneficial by introducing more passive cooling	
Poorly maintained/operated shading	Change shading transmission factor	1.0 for all windows
White roofs allowed to deteriorate	Override absorptivity of roof	What would it be for dirty white?
No cleaning of solar thermal panels	Equivalent to reducing area? Or just remove from calculation?	50%?
Poor staff training in using systems	Covered by adjustments to schedules and set points at activity database level	None

Table 2: Management issues simulated by changes to asset parameters

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"* [13]. 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 tailor 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. This score is calculated on the basis of the data collected by the auditor from the real building.

The tool contains a number of worksheets which address all the energy management issues.

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.

With MBEAT this score is entered into the tool with the model in Asset energy mode. The normalised management score of between 0 and 100 is entered in the current field in the management scores.

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 2**.

The resulting MBEAT outputs are shown in **Figure 3**, 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 noted that operational savings relate to how the building is run and not the quality of the asset.

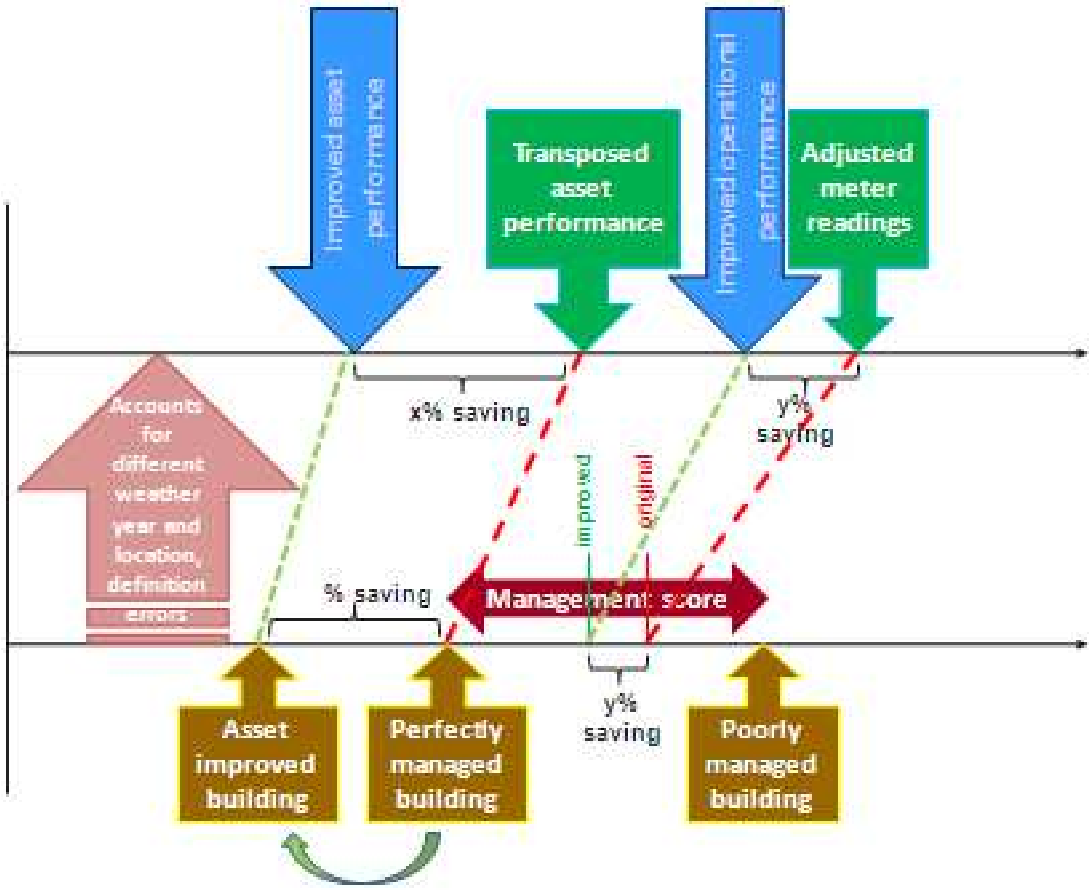

Figure 2: Details of the MBEAT calculations

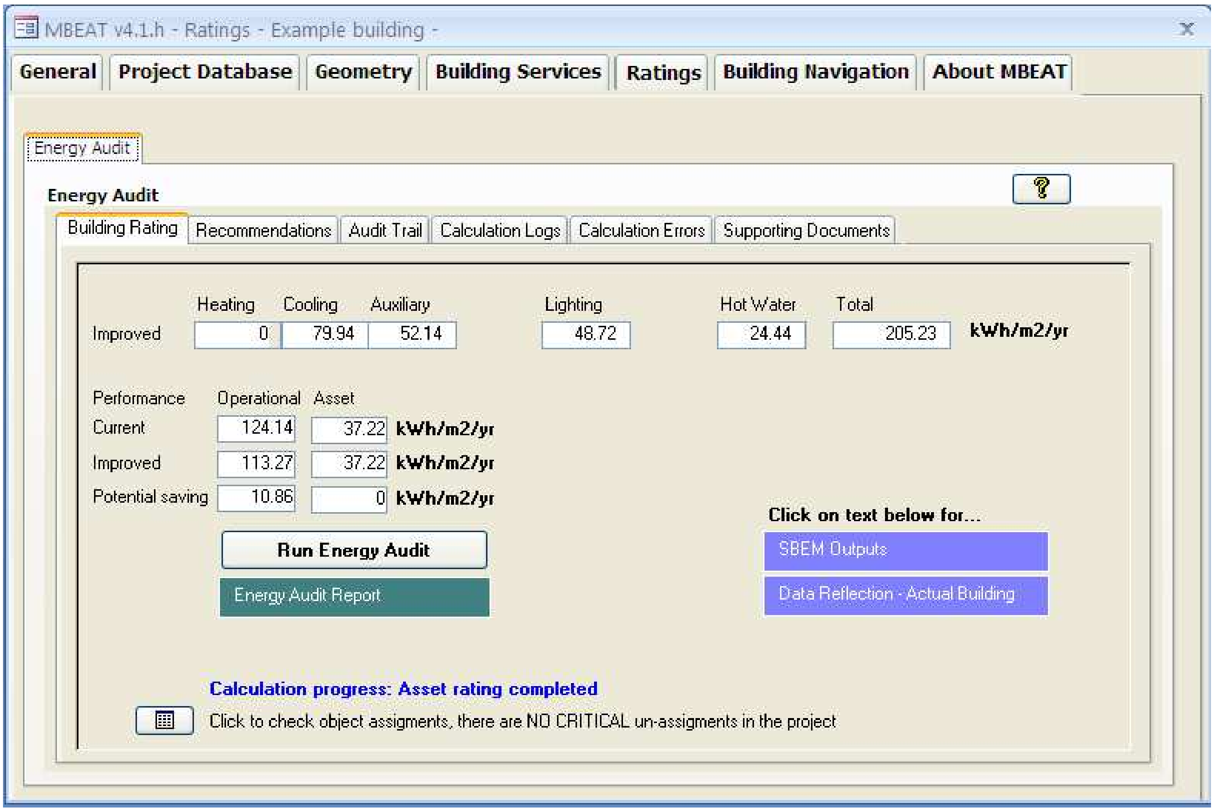

Figure 3: Screen shot of MBEAT ratings Tab

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.

Certain building features are not currently modelled explicitly in SBEM and so representing such features in an adequate way will require somewhat cumbersome data preparation work. This problem is not insurmountable and is most likely to arise where buildings and their systems have features that have properties that vary non-linearly over periods of the order of an hour. Examples of building features where such issues can arise include:

a. Buildings with ventilated double-skin facades;
b. Automatic blind control;
c. Light transfer between highly glazed internal spaces such as atria or light wells.

All calculation processes involve some approximations and compromises, and iSBEM is no exception. The most obvious limitations relate to the use of the ISO monthly heat balance method [14]. 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, iSBEM 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.

MBEAT was designed to be used within the construction types, practices, activities and climate of Mauritius with its scenario of a single serving strategy and fuel type.

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.

Despite its limitations, MBEAT provided a fledgling methodology for linking the Asset and Operational performance of a building and thus bridging the gap between the two measures. The result was 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, indicated 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.

The Green Deal (GD) assessment tool

The MBEAT tool had proved a valuable learning exercise but for this to be imported back into the UK following barriers need to be overcome:

1. How to capture the energy management scores within the iSBEM tool.

2. How to deal with multiple servicing strategies and several fuel types.

This has led to the Green Deal assessment tool abandoning the ideal of a single energy management score for the whole building but instead of having management scores for each individual building object and integrating these within the tool.

The exception being some parameters which are entered at a global level (see **Figure 4**). These are normally overarching organisational issues such as:

i. Delegated responsibly and authority;

ii. Ring fenced budgets;

iii. Metering and monitoring;

iv. Staff awareness and training.

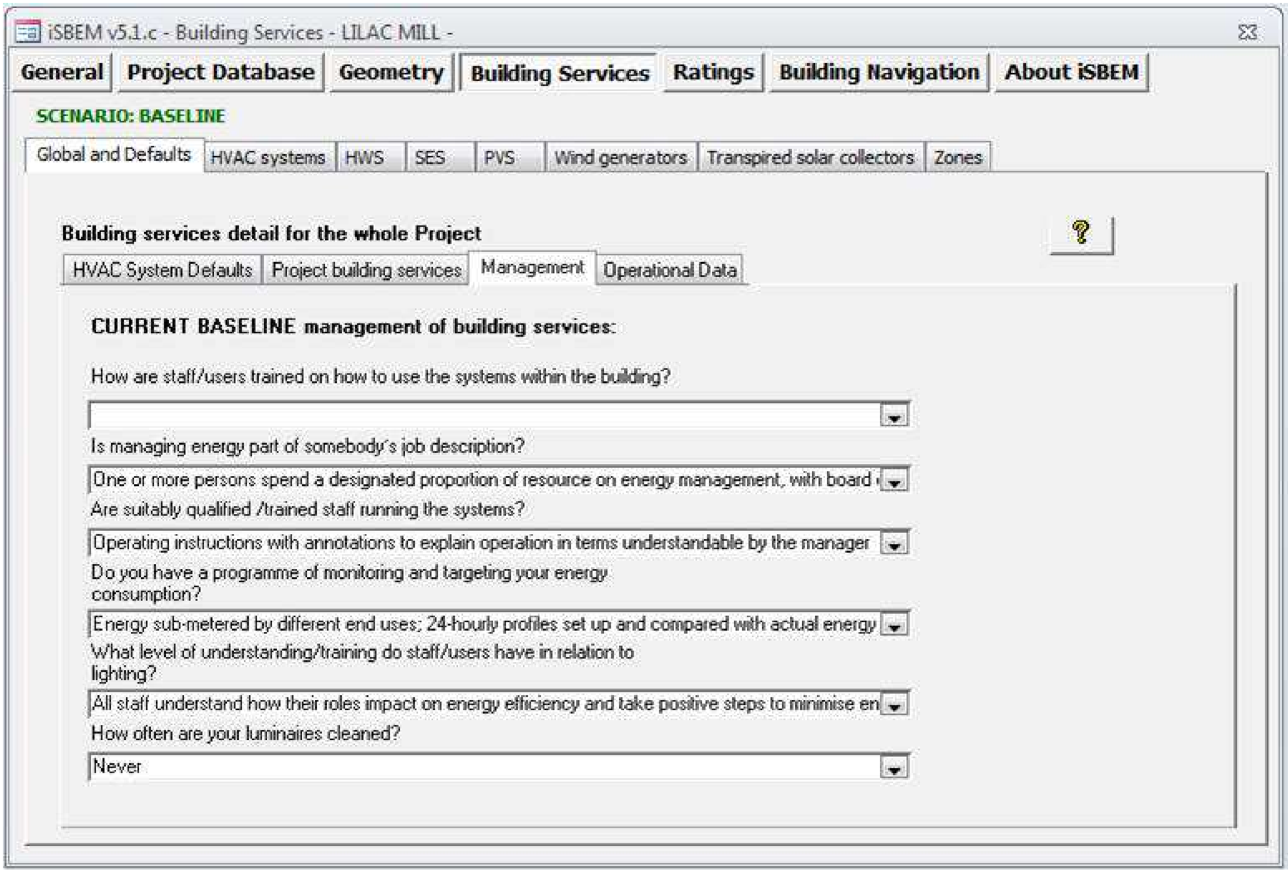

Figure 4: Global energy management parameters

Fabric degradation is dealt with in the geometry management tab where the following are asked:

- Do you have a programme of regular inspection and remedial measures for air tightness?
- Do you have a programme of regular inspection and remedial measures for fixed shading?

The approach of having management scores for each individual building services object provides granularity, as well as taking into account different fuel types because the fuel type is assigned at this level (see **Figure 5** for HVAC systems energy management parameters).

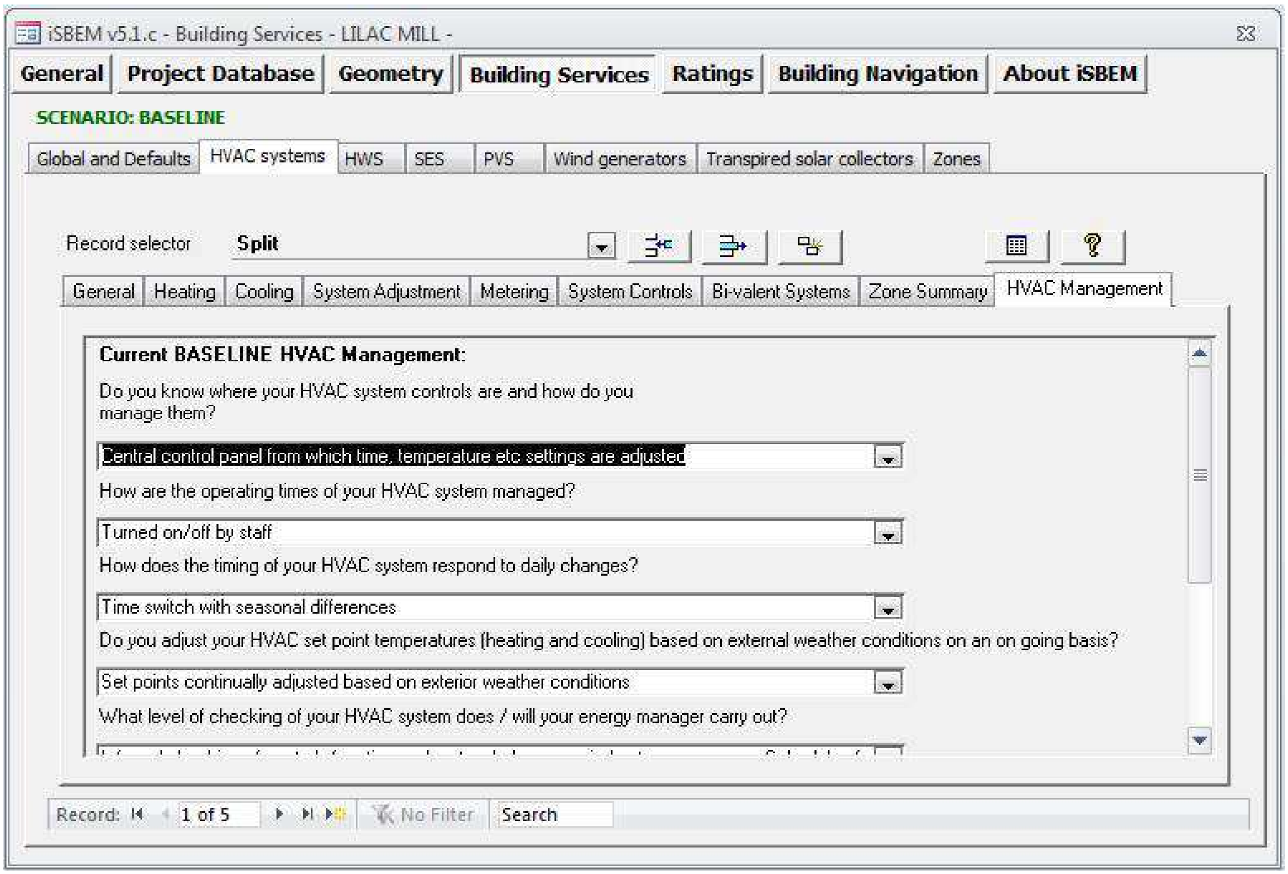

Figure 5: Energy management parameters for HVAC systems

As a result the transposition is done at an object level and then re-aggregated to give the overall level of performance of the building.

Figure 6 shows the Building rating tab of the Green Deal (GD) tool with energy usage broken down into five end uses:

- Heating;
- Cooling;
- Auxiliary;
- Lighting;
- Hot water.

This is done for two scenarios:

1. As the building is actually managed; and
2. As the building could be potentially managed for it to become more energy efficient.

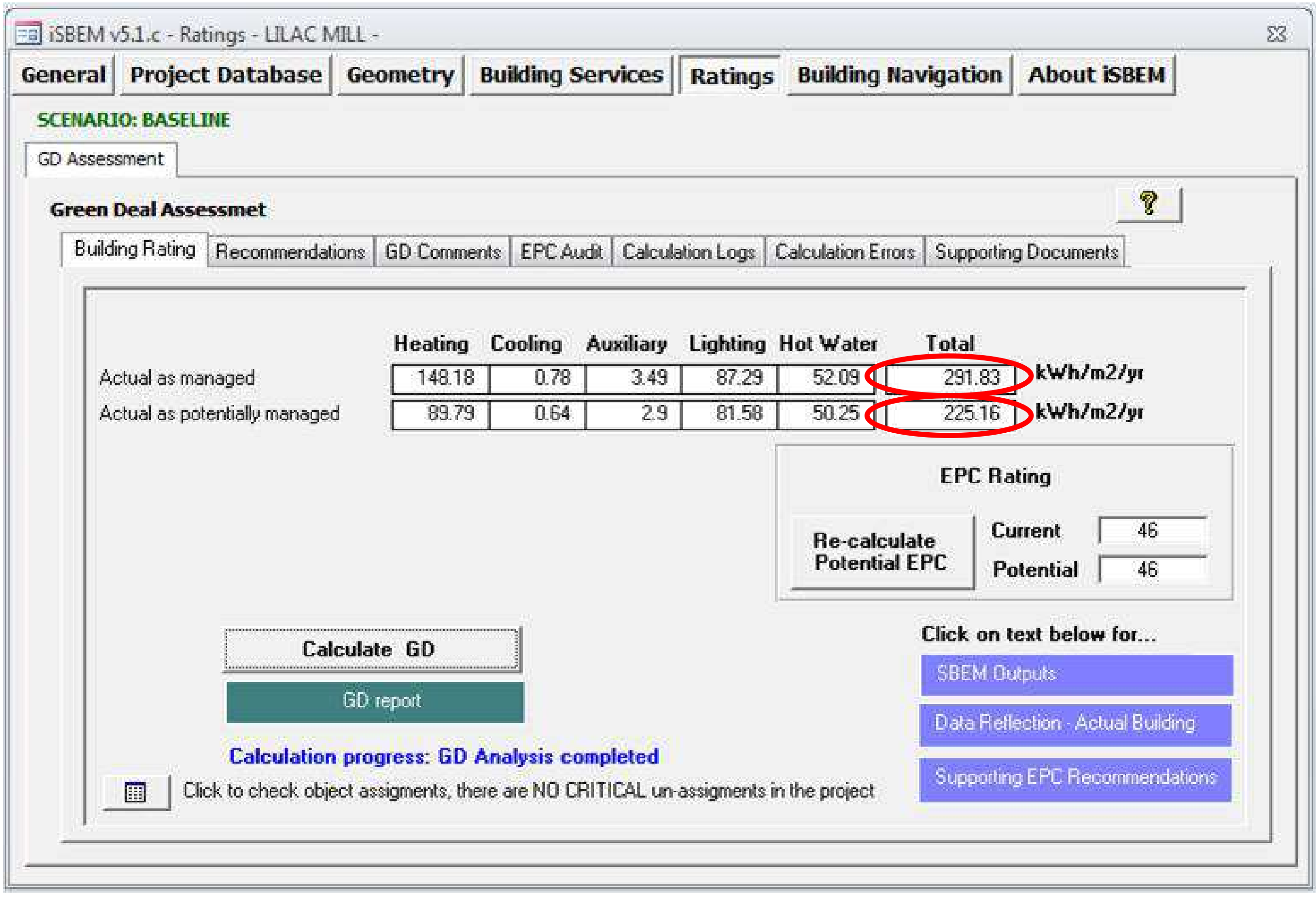

Figure 6: Building rating tab of the Green Deal tool

As earlier mentioned in the paper, it was pointed out that one of the weaknesses of operational ratings was "standard driving conditions" where an apparently high rating was diagnosed as being due to poor management whilst the underlying reasons were high occupancy and hours of use.

The GD tool deals with this by allowing actual occupancy density and hours of occupation to be entered and therefore the operational rating to more closely match reality. Thus dealing with the issue that high people count and long working hours lead to high energy consumption but this is not necessarily a badly managed building.

Figure 7 shows the activities tab with adjustable zone parameters which allows values for occupancy density, heat/cool set points, equipment gains, hot water use, display lighting and lighting start/end times to be entered from on-site data collected by the assessor.

This allows each zone to be tailored to the real life situation along with the hours of use which is entered through the occupancy schedule shown in **Figure 8**.

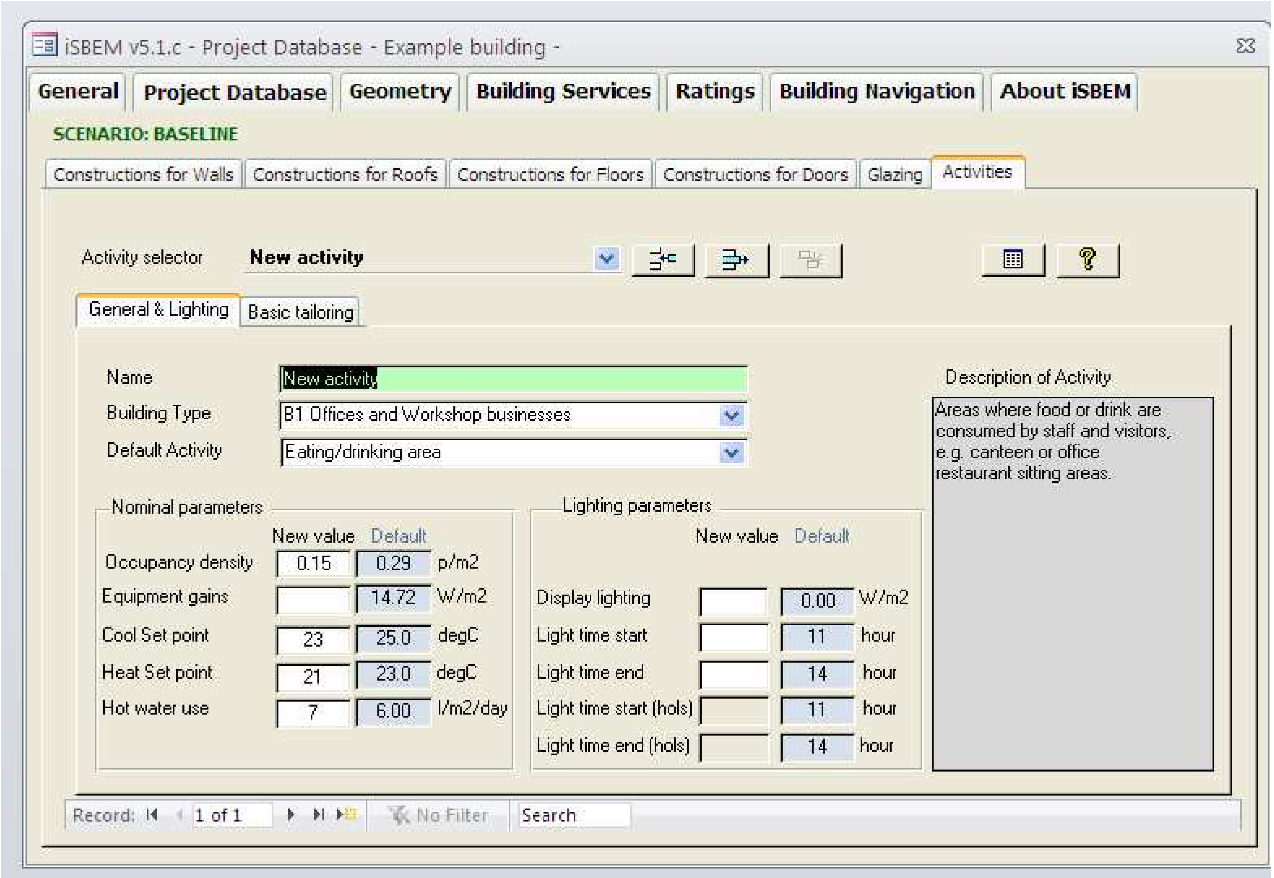

Figure 7: Activities tab with adjustable zone parameters

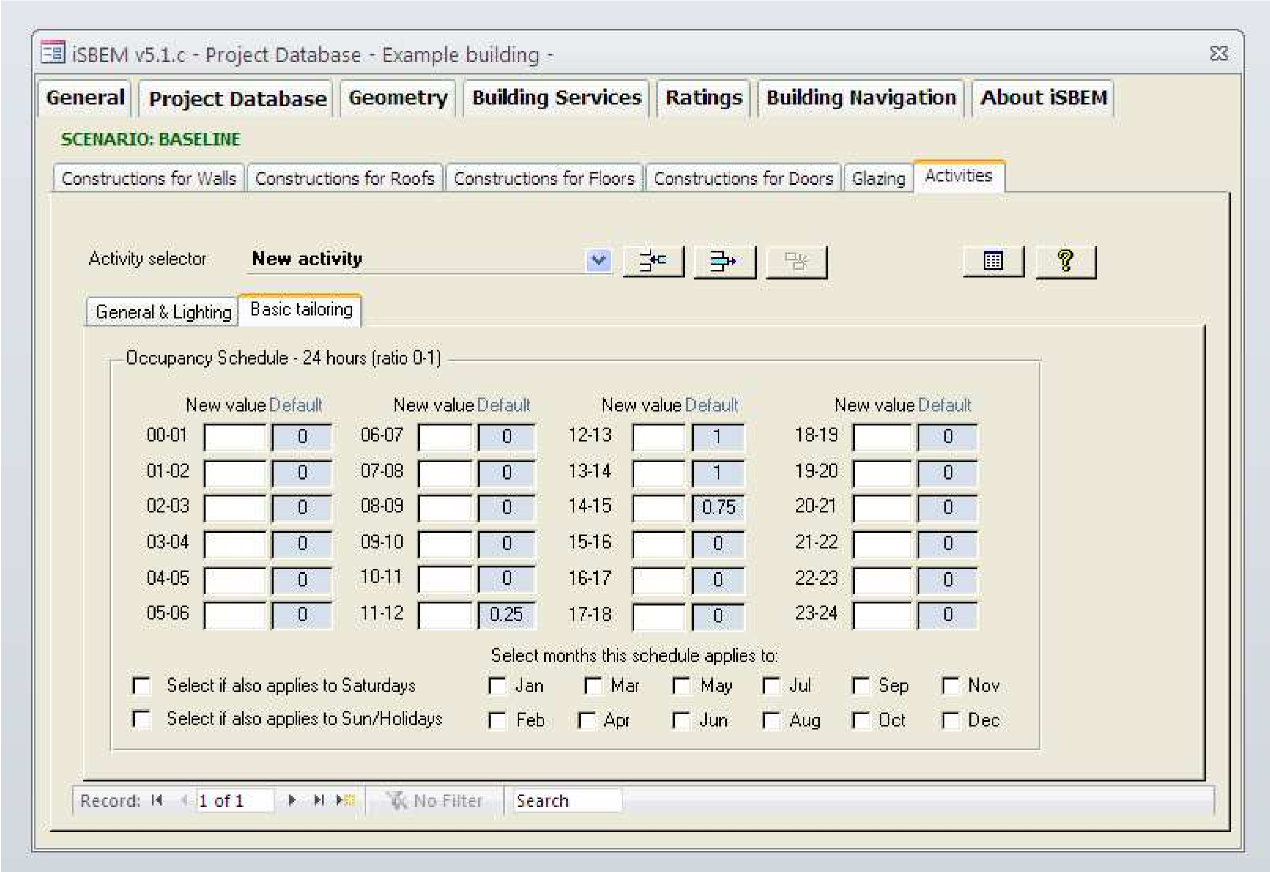

Figure 8: Activities tab with adjustable zone occupancy schedule

The meter readings can then be entered along with the price of the fuel and other operational data – see **Figure 9**.

The programme then calculates an adjusted asset and operational rating (see Figure 2) based on the:

- Degradation of the asset;
- The management of the building;
- Adjusted meter readings - for different weather year, location, occupancy density and hours.

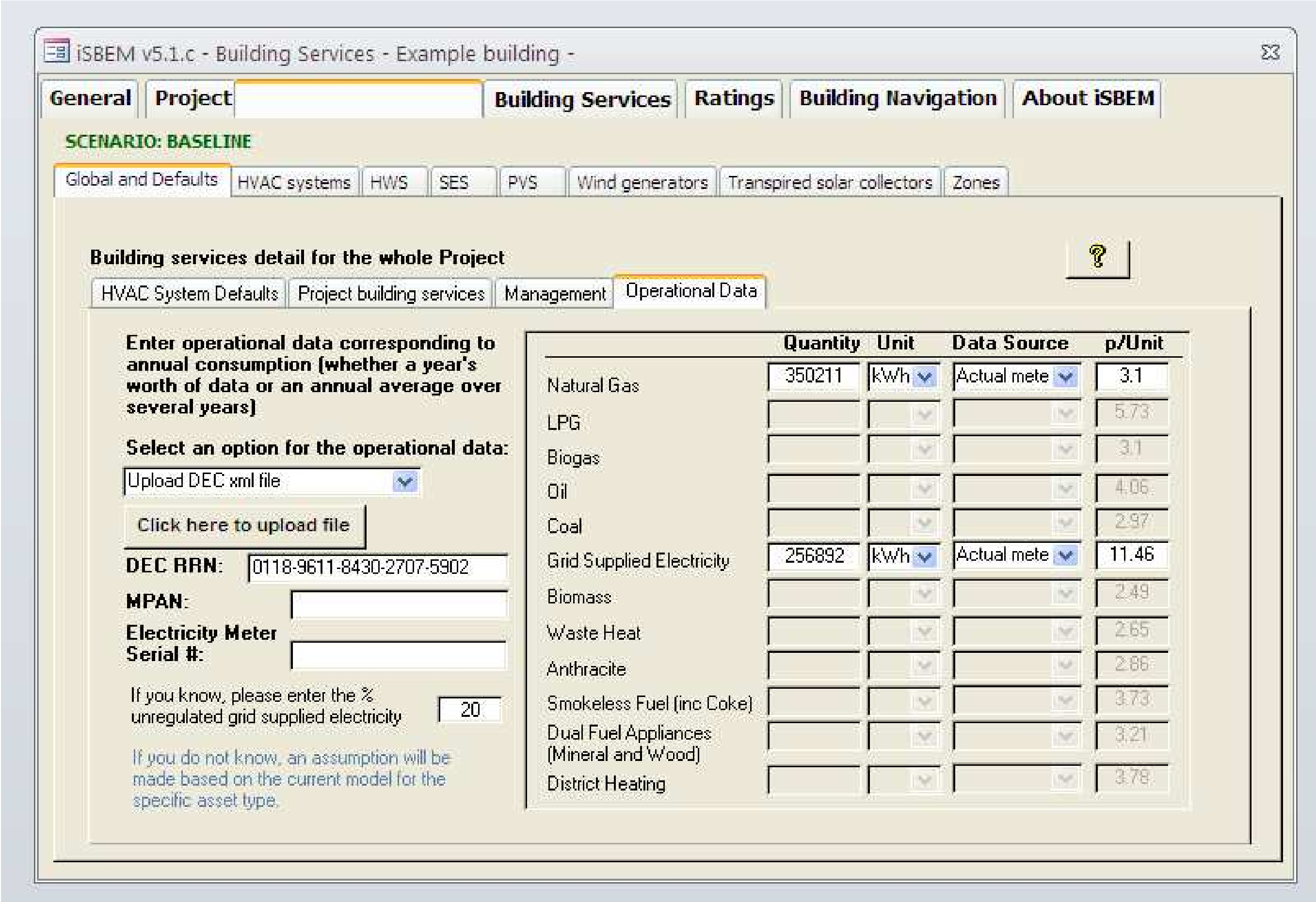

Figure 9: Operational data tab with meter readings

This has led to a tool with a more in-depth picture of energy usage within the building where asset and operational rating can be used to quantify and prioritise investment (see **Figures 9 and 10**) by running before and after scenarios on a range of remedial measures.

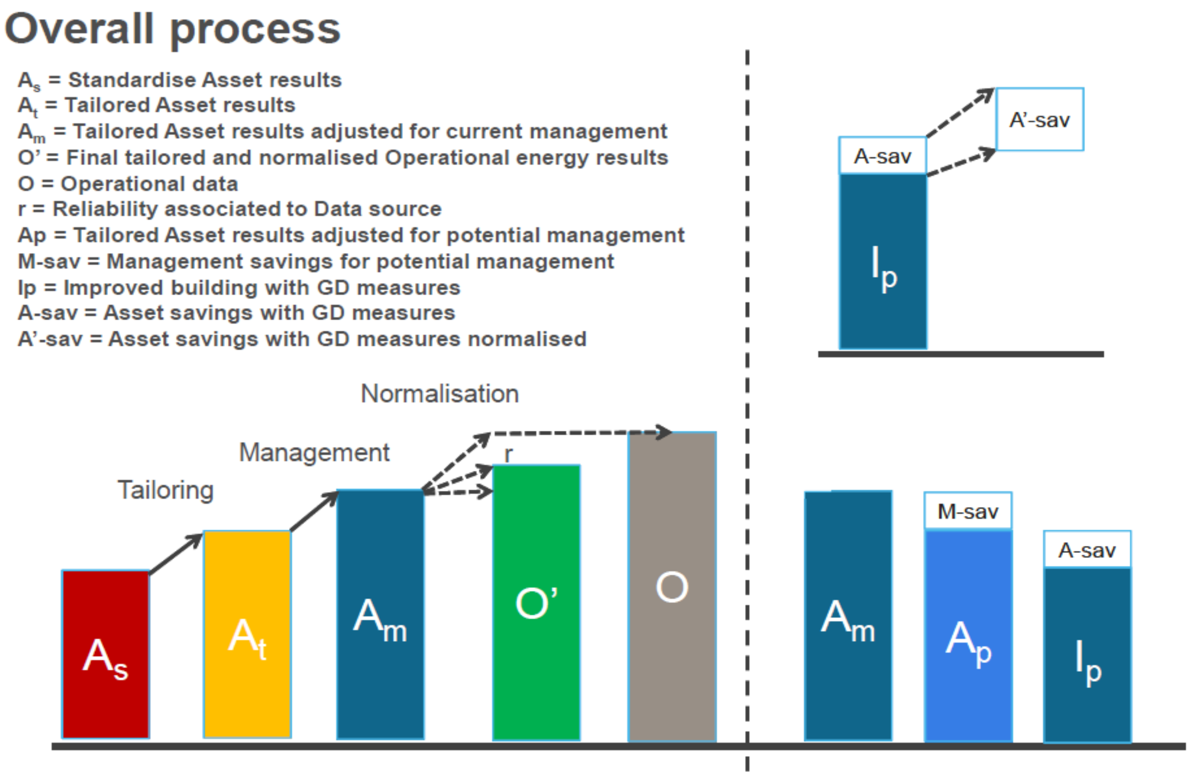

Figure 9: Green Deal Tool overall process

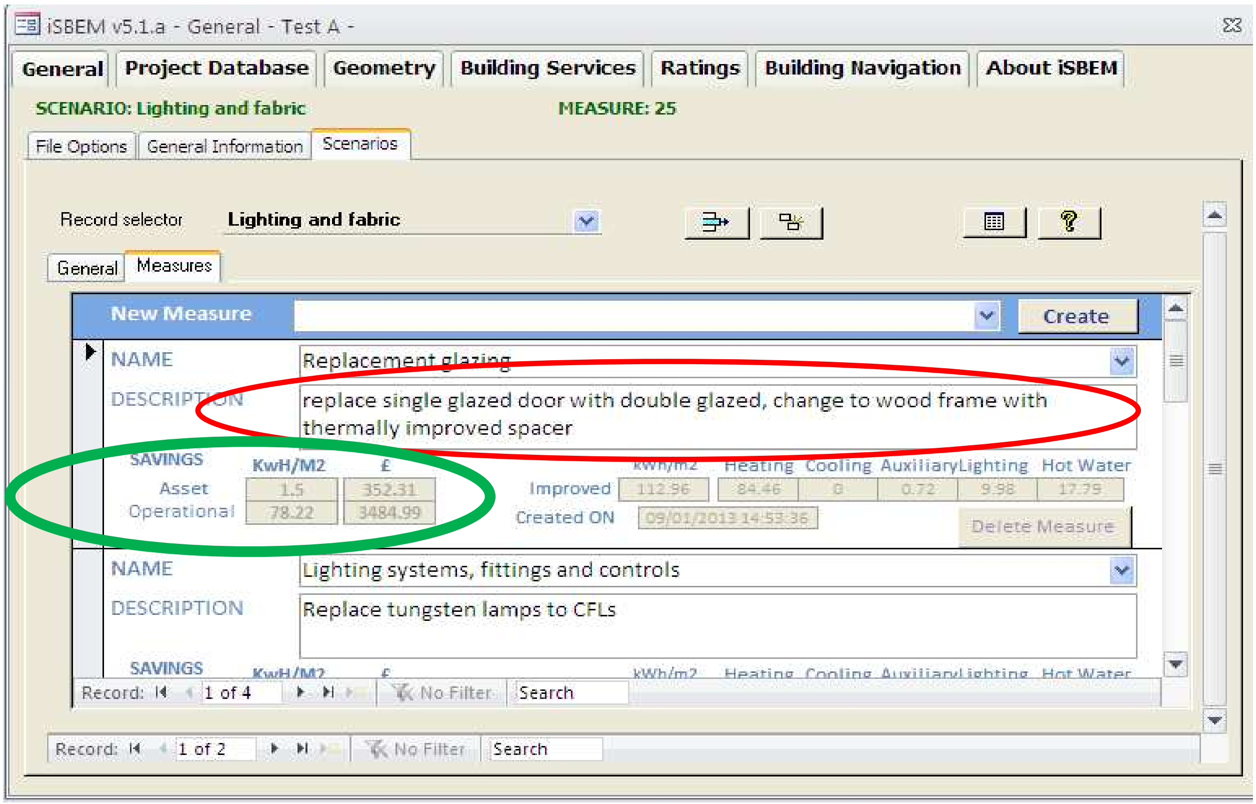

Figure 10: Scenarios tab

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Adapting the principles of Integrated Design to achieve high performance goals: Nearly Zero Energy Building in the European market

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Abstract

The building design phase is of particular importance. Integrated Design (ID) in general is a valuable approach to reduce the complexity of the design process and facilitates the interactions between the members of the design team. For the purpose of reaching high sustainability performance, the alternative building and technical solutions should be developed and discussed by an integrated, multidisciplinary team. It is not limited to energy efficiency and goes beyond this issue. However, ID is not a new notion or concept, but rather an enhancement of good practice as design processes are moving towards greater complexity. The relevance of the concept is based on the well-proven observation that changes and improvements of the design are relatively easy to make at the beginning of the design process, but become increasingly difficult and disruptive as the process unfolds. In this context early design phases offer an opportunity for large impact on performance to the lowest costs and disruption. Therefore, a shift of work load and enhancement to the early phases will probably pay off in the lifecycle of the building. Changes or improvements to a building design when foundations are being poured, or even contract documents are in the process of being prepared, are likely to be very costly and extremely disruptive to the process. Late attempts of improvements are also likely to result in only moderate gains in performance. The IEE project MaTrID – Market Transformation Towards Nearly Zero Energy Buildings Through Widespread Use of Integrated Energy Design – aims at supporting the implementation of Nearly Zero Energy Buildings by 2020 (http://www.integrateddesign.eu/). In order to accelerate the application of ID processes in European countries a clear step by step explanation about the ID approach is necessary. Hence, on the basis of generated knowledge form the project INTEND (http://www.intendesign.com/) we developed an ID Process Guide. The guide will be translated into national context of 11 European partner countries. Also a client and a tenant brief were prepared as well as supplements on scope of services and remuneration models. Furthermore, among European project partners about 20 Integrated Design pilot projects are accompanied and documented. Gathered know-how from those large scale tests will be disseminated and thus set best practice examples which can be easily multiplied. Within the framework of the project the GreenBuilding Integrated Design Award has been launched. ID processes in non-residential buildings from all over Europe are invited to apply annually. The benefit of EU collaboration is to cross-pollinate best practices among leading European countries. On this basis practical recommendations on possible policy instruments that may support the widespread use of Integrated Design on daily design practice.

Keywords
Integrated Design; Integrated Energy Design; NZEB; 20 Pilot projects among 11 European countries; ID Process Guide; GreenBuilding Integrated Design Award

1 Introduction

The global drive towards sustainable development and rising energy prices are putting increasing pressure on building developers and designers to produce buildings with a markedly higher environmental performance. In addition, the building industry is faced with more stringent performance requirements being imposed by markets and regulations.
The recast Directive on the Energy Performance of Buildings (EPBD) stipulates that by 2020 all new buildings constructed within the European Union after 2020 should reach nearly zero energy levels. This means that in less than one decade, all new buildings will demonstrate very high energy performance and their reduced or very low energy needs will be significantly covered by renewable energy sources.

In parallel, member states shall draw up national action plans for increasing the number of nearly zero-energy buildings (NZEB). These national action plans shall include policies and measures to stimulate the transformation of existing buildings which are refurbished into nearly zero-energy buildings. In addition, by 2015 all new buildings and buildings undergoing major renovation must have minimum levels of energy from renewable sources. The implementation of these policy goals requires a major transformation in the building sector during the next few years.
The design of NZEB requires an interdisciplinary approach. Reducing the energy demand in the design phase demands specifications of the different designers and engineers such as architects, building physics or façade designers. For this reason, the introduction of a design team is compulsory for the design of NZEBs.
In this context the building design phase is of particular importance. IED is a valuable assisting approach to reduce the complexity of the design process, to ensure the implementation of defined, to identify pros and cons of alternative variants of design concepts and to allow decision makers to decide based on transparent facts. Only if IED is applied from the very beginning of the design phase we can assume that a cost-effective solution for NZEB can be identified, because only at the early design phases changes of the general design concept can be implemented at low cost. Therefore, the application of IED is part of the best way towards the intended NZEB at low cost.

2 TRANSITION FROM LOW ENERGY TO nEARLY ZERO-ENERGY BUILDINGS

Directive 2010/31/EU (EPBD recast) Article 9 requires that “Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings”. Member states shall furthermore “draw up national plans for increasing the number of nearly zero-energy buildings” and “following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings”.
A nearly zero-energy building is defined in Article 2 of the EPBD recast as “a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”.
To achieve a suitable definition, related facts and findings need to be seen in a broader societal context and need to be transferred into a practical standard, taking into account financial, legal, technical and environmental aspects. Analysing the implications identified above, it becomes obvious that most of them interact or require the consideration of one or several societal aspects. Consequently, the principles for an NZEB definition should be built on the same broad perspective, should take into account all financial, legal, technical and environmental aspects and should meet the present and future challenges and benefits. Hence, a proper and feasible NZEB definition should have the following characteristics (Thomsen, 2011):

- Clear in its aims and terms, to avoid misunderstandings and implementation failures.
- Technically and financially feasible.
- Sufficiently flexible and adaptable to local climate conditions, building traditions, etc., without compromising the overall aim.
- Built on the existing low-energy standards and practices.
- Allow and even foster open competition between different technologies.
- Ambitious in terms of environmental impact and to be elaborated as an open concept, able to keep pace with the technology development.
- Elaborated based on a wide agreement of the main stakeholders (politicians, designers, industry, investors, users etc.).
- Inspiring and to stimulate the appetite for faster adoption.

Consequently, there are three basic principles, each one with a corollary for setting up a proper NZEB definition, addressing the three main reasons and aims for regulating the building sector: reduced energy demand, the use of renewable energy and reduced associated GHG emissions.

1) Energy demand
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.
2) 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.

3) 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.

The achievement of the high performance goals of the implementation of NZEB demands the assessment of the building in a lifecycle perspective both regarding environmental performance (LCA) and costs (LCC). This basis is a major principle of the Integrated Design.

3 the PRINCIPLES OF integrated design

Integrated Design is an approach that considers the design process as well as the physical solutions, and the overall goal is to optimize buildings as whole systems throughout the lifecycle. Firstly, for the purpose of reaching high sustainability performance, the alternative building and technical solutions should be developed and discussed by an integrated, multidisciplinary team. ID emphasizes a decision process rooted in informed choices with regard to the project goals, and on systematic evaluation of design proposals. This approach for building design is paralleling the principles of environmental management referred in the international ISO 14001 standards. Here, identifying and prioritizing goals, and developing an evaluation plan with milestones for follow-up, are central issues.
A shift of approach emphasizes that the very early phases need more attention because well informed decisions here will pay off in the rest of the design process as well as in the lifecycle of the building. Well informed planning from the start can allow buildings to reach very low energy use and reduced operating costs at very little extra capital cost, if any. Considering the whole life cycle of a building, the running costs are higher than construction and refurbishment costs; thus, it becomes obvious that it is a shortsighted approach to squeeze the first design phase regarding resources. Experience from building projects applying ID shows that the investment costs may be about 5 % higher, but the annual running costs will be reduced by as much as 40-90 % (MaTrID workshop, 2013, WBDG 2012). The process of ID emphasizes that the performance of buildings should be assessed in a lifecycle perspective, both regarding costs (LCC) and environmental performance (LCA). Figure 1 indicates the importance of the Integrated Design process at the early phases (Nordby, 2013).

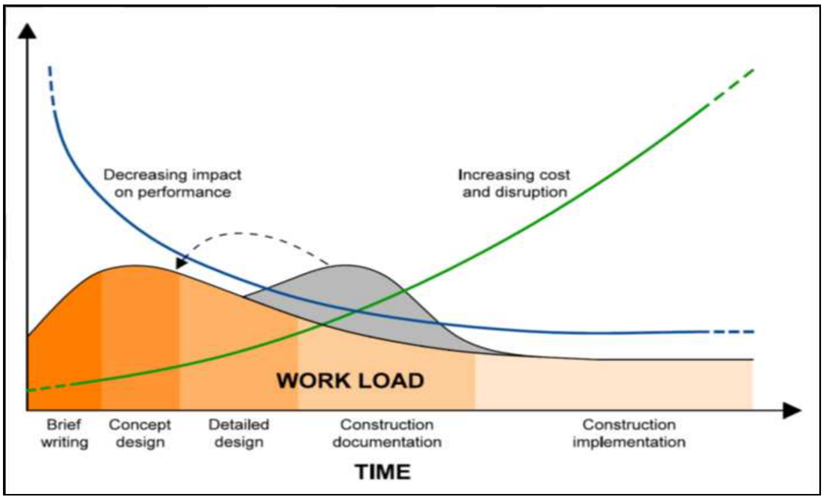

Figure 1. Early design phases offer opportunity for large impact on performance to the lowest costs and disruption. Therefore, a shift of work load and enhancement to the early phases will probably pay off in the lifecycle of the building.

An Integrated Design approach that combines smart, passive design, thermally efficient building skins and effective space planning to reduce energy demands as a first step, combined with highly efficient systems, provides a cost-effective alternative to bolt-on systems installed on an otherwise under-performing building.

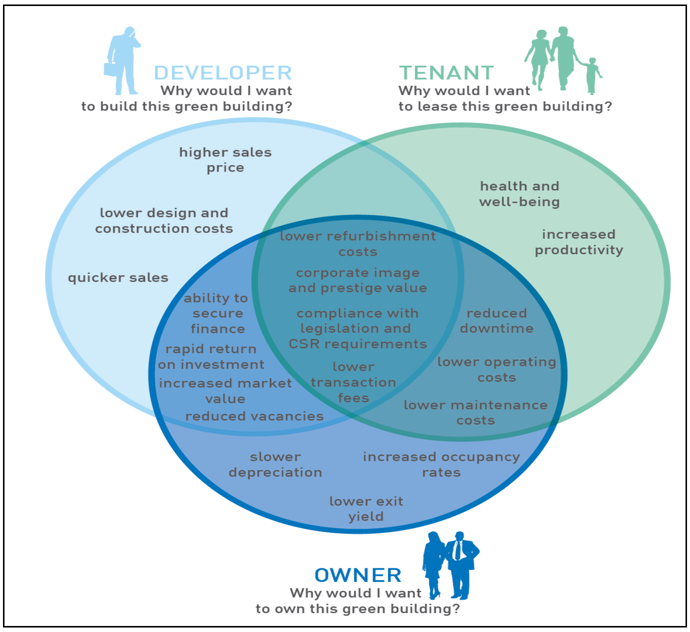

Figure 2. The interplay of Green Building benefits for developers, owners and tenants (WGBC 2013).

In addition to reduced long-term operation and maintenance costs, green buildings are increasingly proven to increase marketability as well as to improve worker productivity and occupant health. And conversely, it is now widely accepted that poor environmental buildings negatively influence building values. In Figure 2, the various benefits of green buildings for developers, owners and tenants are visualized. (WGBC 2013)

3.1 The principles

Six steps can be identified for a successful Integrated Design implementation:

- Project development: discussion of the project ambitions and challenge initial client presumptions, initiating ID process and preferably make partnering contracts.
- Design basis: selection of a multi-disciplinary design team, including an ID facilitator, motivated for close operation, analysis of the boundary conditions. Also refine the brief and specify the project ambitions, preferably as functional goals.
- Iterative problem solving: facilitate close operation between the architect, engineers and relevant experts through workshops etc. Use of both creative and analytical techniques in the design process. Discussion and evaluation of the multiple concepts and finalise optimised design.
- On track monitoring: Use goals/ targets as means of measuring success of design proposals, make a Quality Control Plan, evaluate the design and document the achievements at critical points/milestones.
- Delivery: Ensure that the goals are properly defined and communicated in the tender documents and building contracts, motivate and educate construction workers and apply appropriate quality tests, facilitate soft landing. Make a user manual for operation and maintenance of the building.
- In use: Facilitate commissioning and check that the technical systems etc. are working as assumed, monitor the building performance over time regarding e.g. energy consumption, user satisfaction etc.

3.2 Benefits and barriers

Integrated Design processes result in higher energy performance: optimization of building form, orientation and facades is reached through open multidisciplinary discussions and design decisions in early project phases, where knowledge about important conditions is exchanged to inform the design of the building. It also contributes to the reduction of embodied carbon as optimized design is given priority before advanced technical systems and control mechanisms. Indoor climate is significantly improved: the building and technical systems work together in a logical symbiosis in order to achieve sufficient indoor air quality, temperature control and daylight access/ solar protection. Running costs of the building are reduced: simplified technical systems are more cost efficient, both in terms of

investment costs for manufacturing and installation and in terms of running costs and maintenance. Another aspect is the reduction of risks and construction defects as improved planning leads to less building faults. Thus; less claiming and money saved. Early involvement of users and inclusion of user needs in the design process may improve the following performance of the building in the operation phase, as well as increase user satisfaction. A high performance building can yield higher rental costs which can be compensated for by a lower energy bill thus the sales value of the building will increase. A green image can also benefit the building owner or tenant organization.
Despite the benefits there are certain barriers that need to be addressed as:

1) Conventional thinking
The building sector is known for being slow accepting new ways of working. ID calls for decision processes and design methods that challenge familiar habits, and require high communication skills. Professionals on both sides of the table must practice in collaboration, and maybe adjust their working habits.
2) ID seems to costs too much
Developers traditionally pay more attention to construction costs than lifecycle costs (LCC). However, when energy consumption and maintenance is included in the calculations, it usually supports investments in planning for high performance and robust solutions.
3) Time constraints in initial design phase
Often developers underestimate the value of thoroughly planning, and expect high speed in conceptualizing a building. It can be challenging to convince the developer that the initial phase is crucial, and that giving time for design iterations often pay off in better concepts.
4) "Skills tyranny"
As the ID process requires more collaboration between stakeholders who may have diverging goals, conflicts could be accentuated. It is therefore necessary that the team members do not insist on ultimate demands within their fields of expertise, but rather endeavour to work with a holistic approach.

4 POLICY FRAMEWORK CONDITIONS

In general, the policy framework conditions in most European countries encourages the implementation of Integrated Design despite the fact that ID processes are not mandatory for building projects. Legislation supports and gives incentives for the widespread application while at the same time strong scientific and technical interest has aroused. The goals and the methods though of the assessment have to be clarified and adapted to each country.
In Austria, the national building codes focus on the technical aspects as well as the building process. Codes include regulations for the use of land, rights and duties of builders during the planning and construction process, as well as regulations for the execution and technical requirements of buildings. However, there are no requirements for Integrated Design. At the moment Austrian requirements for the energy performance of buildings are not too high; therefore Integrated Design is not a key aspect for the construction of functional buildings. Both international schemes used in Austria, the American LEED system and the British BREEAM, do not include ID as a assessment criterion, although in LEED there are additional scores available for innovations in design.
For the implementation of Energy Performance of Buildings Directive (EPBD), a Ministerial decision for the new 'Regulation of Energy Performance of Buildings' (KENAK) in Greece has been issued in April 2010 (Ministerial decision D6/B/5825 National Gazette 407). The Presidential decree necessary for the definition of the qualifications and training of energy auditors was published in the National Gazette in October 2010 (Presidential Decree 100/NG177). Full implementation started in January 2011, for all types of buildings and building use, new or existing undergoing major renovation. KENAK is currently being revised and the new version will be issued by the end of 2014.The nearly-Zero Energy Building (NZEB) has been introduced to the national legislation, by amendment, in June 2010 and it coincides with the precise EPBD definition. This definition is also included in the recently elaborated recast of the law for the energy efficiency of buildings. Directive 2010/31/EU (EPBD recast) has been adapted by the Greek legislation Energy Performance of Buildings- Harmonization with the Directive Directive 2010/31/EU (Law Number 4122, National Gazette 42) of February 2013. The law specifies that after 1 January 2019 every new building of the public sector should be NZEB. This obligation is also applied to all new buildings constructed after 1 January 2021.
BREEAM-NOR is the Norwegian version of the Environmental assessment scheme BREEAM. The scheme does not give specific points for ID today, however points are given for using a BREEAM accredited professional (AP) as a facilitator. Common for both approaches is a focus on team-work, timing and quality control in the design process. As the process of BREEAM-certification is similar to ID thinking and the role of a BREEAM AP is very much like the role of an ID facilitator, it could be

discussed if these roles should be merged. In Norway, the building codes are geared towards technical solutions and calculated energy use per square meter, and to some extent on avoiding hazardous materials. Focus on design processes is absent. However, in larger scale planning processes/ zoning, the process is firmly predefined and includes public hearings etc. to ensure that the various affected parties can express and advocated their interests. With reference to planning processes, it could be argued that optimal design of buildings (public as well as private) is in the public interest and depends on predefined and cleverly managed design processes.
A specific focus on the design process is absent in Italy, but, just for public buildings, the Decreto del Presidente della Repubblica (DPR) n. 207 published on 5/10/ 2010, obliges to verify the projects to be put out to tender, which are not yet approved. In particular, this law specifies that the verification of the project is designed to ensure the compliance of the chosen design solutions with the specific functional, performance, normative and technical provisions, contained in the feasibility study, preliminary design document or in the conceptual design. Several Environmental assessment schemes are used in Italy although their adoption in not mandatory on the whole national territory. The most adopted Environmental assessment schemes in Italy are the 'ITACA Protocol' and the 'LEED Italy'.

5 the matrid project

MaTrID aims to support the implementation of Nearly Zero Energy Buildings by 2020. In this context the building design phase is of particular importance. Integrated Energy Design (IED) is a valuable approach to reduce the complexity of the design process and facilitate the interactions between the members of the design team. IED allows them to provide the best solution for the whole building. MaTrID's targets are harmonized with the Integrated Design process as described in the previous section. (Leutgöb, 2012)

5.1 Objectives

The objectives of the proposed project have been identified based on a holistic IED approach. Activities are needed on the side of the building owner (developer) as well as on the side of designers. Starting from this, the following specific project objectives can be derived:

1) Establishing the general understanding on the advantages and requirements of IED at the side of real estate developers and building owners: In this context, the project aims at convincing opinion leaders of builder's associations, big property developers or other multipliers that IED is the way to be chosen for the design of cost-efficient NZEB.
2) Improving the know-how basis on IED: The application of IED requires practical know-how on the developer's side as well as on the designers' side. Therefore the project aims at developing practical tools, such as specific text modules for client briefs as well as for IED related contracts and remuneration models.
3) Testing the practical implementation of IED on a large scale thus setting best practice examples which can be easily copied and multiplied
4) Development of a common tool-kit for the integrated energy design of NZEB
    - Clients brief for NZEB
    - IED-related model contracts
    - IED-friendly remunerations models
    - User-friendly IED guideline
5) Adaptation of the common tool-kit to national requirements
6) Implementing EU-wide promotion and dissemination activities
7) Drawing conclusions for a further market adoption of IED in the years after the end of the project including also practical recommendations on possible policy instruments that may support the widespread use of IED on daily design practice.

5.2 Focus area

The construction, architects and engineering market is very much focused on regional and local level. Additionally, the state of the art for IED in the participating countries is very different. For this reason, the emphasis of the project is on widespread market adoption on national level. National activities are country specific and reflect the respective demand.

5.3 Benefits

The greatest benefits are provided only if applied in the earliest stages of the project, when changes to the design are still easy to implement. The benefit of EU collaboration is to cross-pollinate good practices among leading European countries (including clients, private industry, public sector, etc.). Knowledge transfer among Europe and various actors is the main benefit of MaTrID.

5.4 Outcomes

The outcomes of the project can be summarised as follows:

- A general understanding on the advantages and requirements of IED on the part of real estate developers and building owners as well as on the designers' side.
- Practical tools – such as specific text modules for client briefs as well as for IED related contracts and remuneration models – which can be directly applied in daily practice.
- Successfully tested pilot projects with practical implementation of IED on a large scale. Examples can be easily copied and multiplied.
- General acknowledgement of IED beyond the limits of the participating countries.
- Conclusions for a further market adoption of IED in the years after the end of the project including also practical recommendations on possible policy instruments that may support the widespread use of IED on daily design practice.

In order to increase the visibility of the Integrated Design approach, the GreenBuilding Integrated Design Award (GB ID Award) has been launched in the framework of the European GreenBuilding programme and the European project MaTrID. The GB ID Award aims to highlight the use of exemplary ID processes in design and construction.

6 Conclusions

The European Union (EU) aims at drastic reductions in domestic greenhouse gas (GHG) emissions of 80% by 2050 compared to 1990 levels. The building stock is responsible for a major share of GHG emissions and should achieve even higher reductions of at least 88% - 91%. Therefore, without consequently exploiting the huge savings potential attributed to the building stock, the EU will miss its reduction targets. More than one quarter of the 2050s building stock is still to be built. The energy consumption and related GHG emissions of those new buildings need to be close to zero in order to reach the EU's highly ambitious targets. The recast of the Energy Performance of Buildings Directive (EPBD) introduced, in Article 9, "nearly Zero -Energy Buildings" (NZEB) as a future requirement to be implemented from 2019 onwards for public buildings and from 2021 onwards for all new buildings
Integrated Design (ID) is necessary in managing the complex issues arising from planning buildings with high energy- and environmental ambitions. In these processes, emphasis is on collaboration in multidisciplinary teams as well as on clear goal-setting and systematic monitoring. In the early design phases, the opportunity to positively influence building performance is great, while cost and disruptions associated with design changes are very small.
The guiding strategic objective of the MarTrID project is to contribute significantly to a widespread market adoption of integrated energy design of buildings. IED should become the standard way of European building design within 2020. As a result real estate industry will find it easier to cope with the challenges coming from energy and climate change policy by producing sustainable buildings with very high energy performance in a cost-effective way, calculated over the life cycle of the building.

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WBDG (Whole Building Design Guide) Case Studies and High Performance Building Database 2012 http://www.wbdg.org

Evaluation of the European status towards the achievement of nearly zero energy buildings (nZEBs)

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Abstract

The European strategy aimed at 2020 goals is mainly focused on implementation of nearly zero energy buildings (nZEBs) as building target from 2018 afterwards.

The aim of this paper is to provide an overview on the current European status of nZEBs categories, definitions, and calculation methodologies. Many open issues are presented and discussed to contribute to the clarification and the establishment of agreed definitions.

The paper reports the progress towards the implementation of nZEBs and it underlines the effort and the urgency to integrate the nZEBs notion into national building codes and international standards. It also shows how this topic has gained a growing attention in the last decade, but the achievement of a common agreed nZEBs concept is still far to be reached in most of the Member States (MS).

1. Introduction

Commercial and residential buildings are globally estimated to consume approximately 40% of primary energy and to be responsible for 24% of greenhouse emissions [1]. As a consequence, a reduction of the energy demand in buildings can lead to a 20% potential reduction of their impact on the environment.

Specific measures to reduce energy consumptions in the building sector have been introduced by the European union with the Energy Performance of Building Directive (EPBD) in 2002 [2] and its recast in 2010 [3].

Article 9 of the EPBD states that Member States (MS) shall ensure that new buildings occupied by public authorities and properties are nearly zero energy buildings (nZEBs) by December 31, 2018 and that new buildings are nZEBs by December 31, 2020. Furthermore, the EPBD recast establishes the assessment of cost optimal levels related to minimum energy performance requirements in buildings of different European countries [4], [5].

Therefore the importance to integrate the nZEBs concept into national building codes and international standards is widely recognized [6].

In recent years, the topic of nZEBs has been widely analysed and discussed especially within the European Union [7], but it is still subject to discussion at the international level on possible nZEBs boundaries and calculation methodologies [8].

A nZEB is a building that "has a very high energy performance with a low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" [3].

However, the EPBD recast does not give minimum or maximum harmonized requirements neither details of energy performance calculation. Consequently, it will be up to the MS to define what “a very high energy performance” and “to a very significant extent by energy from renewable sources” for them exactly constitute.

Due to the general guidance given by the EPBD recast, an open issue is how to combine nZEBs implementation with cost optimal requirements or how to carry out performance level calculations in an harmonized way in each MS .

What is still missing is a formal, comprehensive and consistent framework that considers all the relevant aspects characterising nZEBs and allow each country to define a consistent definition in accordance with the country's politicy targets and specific conditions [9]. Therefore, a common agreed definition can be seen as a first step towards the nZEB target laid down in EPBD recast [10].

2. nZEBs categories

The discussion around nZEBs has become more debated in the last decade [11].

The term ZEB can be used in reference to a Zero Energy Building and Zero Emission Building. The first refers to the energy consumed by a structure in its day-to day operation, the second is referred to the carbon emissions that are released to the environment as a result of its operation.

In general terms, a Zero Energy Building can be described as a residential or commercial building with greatly reduced energy needs and/or carbon emissions, achieved through efficiency gains, such as the balance of energy needs supplied by renewable energy [12].

Another category of ZEB was introduced by Lausten [13] who distinguished between Autonomous ZEB and Net ZEB. An autonomous ZEB is a ZEB that "does not require connection to the grid or only as backup. Stand-alone buildings can supply their own energy needs, as they have the capacity to store energy for night-time or winter-time use". A Net ZEB is "energy neutral over a year, meaning that it delivers as much energy to the supply grids as it draws from these grids. Seen in these terms, they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid".

In Torricellini et al. [14], a distinction is made in function of the boundary and the metric. However, different definitions maybe needed, depending on the project goals, design principles and building owner. The authors distinguished four different concepts around zero energy buildings: Net Zero site Energy, Net Zero Source Energy, Net Zero Energy Costs and Net Zero Energy Emissions.

A Net Zero Site Energy building is as a building that produces the energy that is used at its location. A hierarchy of renewable energy preference, with energy efficiency at the top and then use the renewable energy sources available on site, is also provided.

Furthermore, an Energy Plus Building (+ ZEB) produces more energy from renewable sources than it imports from the supply grid over a year.

Lund et al. [15] distinguish four types of ZEBs in reference to the energy demand and the installed renewable typology. A PV-ZEB is a building with a relatively small electricity demand and a photovoltaic installation, a Wind-ZEB has a relatively small electricity demand and a small on-site wind turbine, a PV-Solar Thermal-Heat Pump ZEB is characterized by a relatively small heat and electricity demand as well as by a photovoltaic installation in combination with a solar thermal collector, a heat pump and heat storage, while a Wind-Solar Thermal-Heat Pump ZEB has a relatively small heat and electricity demand and it has a wind turbine in combination with a solar thermal collector, a heat pump and heat storage.

3. nZEBs definitions

The main nZEBs distinctions can be done in function of: boundary, period and type of balance, type of energy use, metric and renewable supply options. One of the most important point of discussion is the metric of balance. More than one unit can be used in the definition or in the calculation methodology. The most frequently applied unit is primary energy while the easiest unit to implement is final or delivered energy. Among the other options there are: end use or un-weighted energy, CO_2 equivalent emissions, and the cost of energy.

The period of the balance over which the calculation is performed can vary very much. It can be monthly, seasonal or annual, or the full life cycle of a building or its operating time. The type of energy use is also subject to discussion. In practise, the methods for computing the energy use of a building are very diverse and include many options. Most definitions only cover operational energy (heating, cooling, lighting, ventilation, hot water) and omit embodied energy form calculation. However, the energy required for building material manufacture, maintenance and demolition can be sometimes considerable.

According to the international standard EN 15603: 2008 "Energy performance of buildings – overall energy use and definition of energy rating" [16], the energy rating calculation should include only the energy use that does not "depend on the occupant behaviour, actual weather conditions and other (indoor and environment) conditions", such as heating, cooling, dehumidification, ventilation, humidification, hot water and lighting (for non-residential buildings).

As regards the type of balance, the energy use has to be offset by the renewable energy generation in the off-grid ZEBs, while two possible options are possible in grid-connected ZEBs. The first is more applicable during the design phase of the building and balances the energy use with the renewable energy generation. The second is more applicable during the monitoring phase as it balances the energy delivered to the building with the energy feed into the grid.

The renewable energy supply can be on-site or off-site depending on the availability on site (sun, wind) or to be transported to the site (biomass). Torricellini et al. [14] propose a ranking of preferred application of renewable energy sources (Table 1).

Table 1: ZEB renewable supply option hierarchy (source [14]).

Option no.	ZEB supply side options	Examples
0	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling
On-site supply options 1	Use renewable energy sources available within the building footprint	PV, solar hot water, and wind located on the building
2	Use renewable energy sources available at the site	PV, solar hot water, low impact hydro, and wind located on site, but not on the building
Off-side supply options 3	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or wasted streams from on-site processes that can be used on-site to generate electricity and heat
4	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other "green "purchasing options. Hydroelectric is sometimes considered

Another issue is the possible connection to the energy infrastructure. Most nZEBs definitions imply the building's connection to one or more utility grids. These can be an electricity grid, a district heating and cooling system, gas pipe network, or a biomass and biofuels distribution network. Therefore, buildings have the opportunity to both import and export energy from these grids and thus avoid on-site electricity storage.

While on-grid nZEBs are connected to one or more energy infrastructures using the grid both as a source and a sink of electricity, off-grid nZEBs need an electricity storage system in peak load periods or when RES are not available.

The requirements related to energy efficiency, indoor climate and building-grid interaction can be also determinant in grid connected nZEBs.

Sartori et al. [9] claim that different nZEBs definitions are possible. Each country should develop its own definition in accordance with its unique context. However, many of the EU participant countries have not yet adopted an official definition of a nZEB.

The Rehva Task Force "Nearly Zero Energy Buildings" [17] [18] has recently published a comprehensive definition of nZEBs based on energy flows taken into account for primary energy calculation (Figure 1). The detailed system boundary modified from EN 15603:2008 [15] is used with the inclusion of on-site renewable energy production within the system boundary. This inclusion follows the EPBD recast requiring that the positive influence of on-site renewable energy production is taken into account.

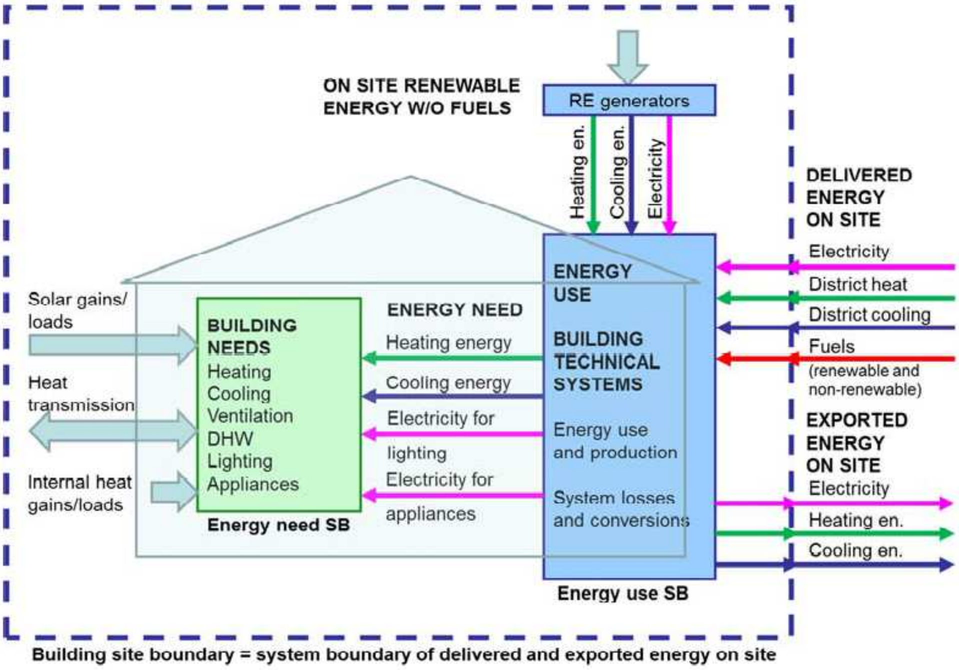

Fig.1: Three system boundaries (SB) for on-site assessment, for energy need, energy use and delivered and exported energy calculation. System boundary of energy use also applies for renewable energy ratio calculation with inclusion of RE from geo-, aero- and hydrothermal energy sources of heat pumps and free cooling (Source: [18]).

A study by the Buildings Performance Institute Europe (BPIE) analyses the differences in Member States between existing methodologies, including floor area, internal heat load, energy uses, conversion factors, external climate condition, indoor temperatures and renewable energy sources [19].

The most common choice adopted in MS is primary energy as a metric expressed in kWh/m2y as a percentage of the minimum requirements given by national building codes [20]. The energy uses included vary widely between the different methodologies. The criteria most widely shared among European countries' methods have been identified and compared in [21], [7]. The most common choices by Member States include primary energy as balance metric, annual as balance period and on site as supply options.

4. nZEB balance concept

The ZEB balance can be calculated as in the equation (1):

$$\text{Net ZEB balance} : |\text{weighted supply}| - |\text{weighted demand}| = 0 \quad (1)$$

where absolute values are used simply to avoid confusion on whether supply or demand is consider as positive [9].

The balance can be represented graphically as in Figure 2, plotting the weighted demand on the x-axis and the weighted supply on the y-axis.

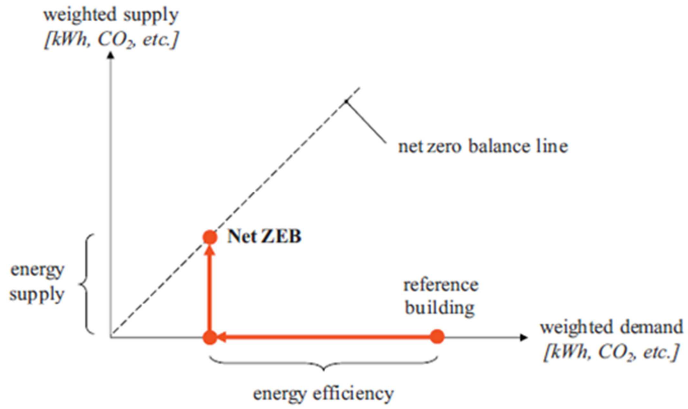

Fig.2: Graph representing the net ZEB balance concept (Source: [9]).

According to the authors, the Net ZEB is given by the reduction of the energy demand (x-axis) by means of energy efficiency measures and the generation of electricity as well as thermal energy carriers by means of energy supply options to get enough credits (y-axis) to achieve the balance.

In most circumstances major energy efficiency measures to reduce demand are needed as on-site energy generation options are limited, e.g. by suitable surface areas for solar systems, especially in high-rise buildings.

Other possible balances are shown in Figure 3, and include the import/export balance between weighted exported and delivered energy, the load/generation balance between weighted generation and load, and monthly net balance between weighted monthly net values of generation and load. A complete set of equations for the different balances are reported in [9].

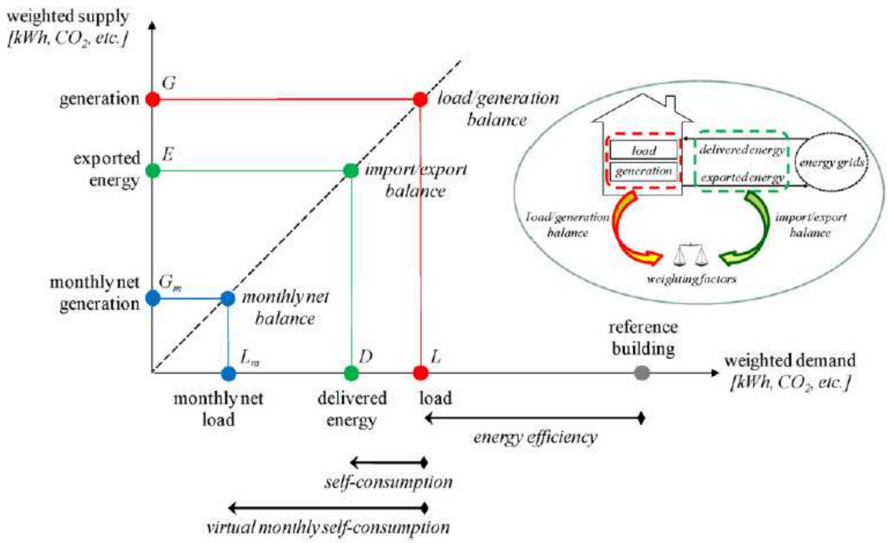

Fig.3: Graphical representation of the three types of balance (Source: [9]).

The authors point out that the three balances differ by the amount of on-site energy generation which is self-consumed or 'virtually' assumed as self-consumed. The graph in Figure 3 shows that the load/generation balance gives the points for weighted demand and supply most far away from the origin. On the other hand, the import/export balance and monthly net balance get closer to the origin as a consequence of the self-consumption and virtual monthly self-consumption. The import/export balance is expected to be always in between the two other, due to the fact that there is usually some amount of self-consumption [9].

Dall'O' et al. [20] propose to calculate the energy balance over one year using the following equation (2):

$$\sum_{m=1}^{12}(EP_G - EP_{RE} - EP_{GP})_m = 0 \quad (2)$$

where EP refers to the specific primary energy (KWh/m2y), and the subscripts G, RE, and GP refer to the global energy, energy linked to renewable source, and the green purchase, respectively. Furthermore, the global specific primary energy EPG can be calculated as in equation (3):

$$EP_G = EP_H + EP_W + EP_C + EP_{EL} \quad (3)$$

where the subscripts H, W, C, EL refer to heating, water, cooling and electricity, respectively. Equation (2) highlights the energy needed to neutralise energy requirements that could be compensated by primary energy from renewable sources (EPRE) as well as by certified purchased green energy (EPGP) (that is also energy produced from renewable sources). The amount of primary energy offset by the purchase of green energy must be at most equivalent to the primary energy produced from renewable sources (EPRE). Thus, off-site renewable energy is allowed, but it must be certified and is limited to a defined value.

5. nZEBs implementation

The European Directive EPBD, together with the Energy Efficiency Directive (EED, 2012/27/EU) and the Renewable Energy Directive (RED, 2009/28/EC), set out a package of measures that create the conditions for significant and long term improvements in the energy performance of Europe's building stock. The EU legislative framework for buildings led a number of European countries to adopt nZEBs definitions and adopt national policies for their implementation.

MS are required to draw up national plans for increasing the number of nZEBs, with targets that may be differentiated according to different building categories. According to paragraph 3 of Article 9, these plans shall include:

- A definition of nearly Zero-Energy Buildings, reflecting national, regional or local conditions and include a numerical indicator of primary energy use, expressed in kWh/m2 per year;
- Intermediate targets for improving the energy performance of new buildings by 2015;
- Information on policies, financial or other measures adopted for the promotion of nZEBs, including details on the use of renewable sources in new buildings and existing buildings undergoing major renovation (Article 13(4) of Directive 2009/28/EC and Articles 6 and 7 of Directive 2010/31/EU).

Furthermore, paragraph 2 of Article 9 asks MS to show a leading example by developing particular policies and measures for refurbishing public buildings towards nearly zero-energy levels and to inform the Commission of national plans [22].

The Concerted Action EPBD project has a regular survey on the implementation of the EPBD requirements in the EU MSs. Many MSs reported ongoing preparatory studies or the intentions to start working on the nZEB over 2013 or later [23]. Belgium/Brussels Region published in September 2011 an amendment of the Energy Performance of Buildings Ordinance [24] which stipulates that from January 2015 onwards, all new public and residential buildings have to fulfill a primary energy need at level of Passive House standard.

The Danish Building Research Institute analysed existing official and non-governmental European definitions of low-energy buildings [20]. This study showed that seven countries have an official definition of very-low-energy buildings, seven countries have an official definition planned, four countries have an existing non-governmental definition, and four countries have both definitions [25].

Figure 4 shows an overview of the status of nZEBs implementation in the 27 EU MS.

Fig.4: Overview of the status of Near ZEB implementation in the 27 EU MS (based on CA EPBD survey 2012). Source: [26].

Among the MS who had been already established general strategies or aims on nZEBs definitions, there are: Denmark, the United Kingdom, France, Germany and Belgium [26].

Denmark is one of the first EU countries that had already set-up their national nZEBs definition and roadmap to 2020 [22]. The minimum energy performance requirements from set buildings regulations will gradually become stricter, starting from the actual standard, BR10 [27], with an interim milestone in 2015 and a final target in 2020. The energy scope includes the energy need for heating, ventilation, cooling, domestic hot water and for the auxiliary equipment. For non-residential buildings, the energy for lighting is also included within the regulated energy. The improvement of the energy performance is done by increasing the requirements for buildings insulation.

Belgium/Brussels Region amended in 2011 the Energy Performance of Buildings Ordinance [24] stipulating that from January 2015 onwards, all new public and residential buildings have to fulfill a primary energy need at level of Passive House standard. The requirement established that residential buildings will have a primary energy consumption for heating, DHW and auxiliary energy below 45kWh/m2/yr and heating need below 15kWh/m2/yr, the latter being equivalent to one of the passive house requirements.

In France low energy requirements were adopted in the recast of the French thermal regulation, RT 2012, which is already applied for new non-residential buildings and since January 2013 also for new residential buildings. The requirement addresses the building's energy need for space heating, domestic hot water, cooling, lighting and auxiliary energy. RT 2012 set the minimum performance requirements at 50 kWh/m²/yr in primary energy. The minimum energy requirement is adjusted by climatic zone and altitude and hence varies between 40 and 65 kWh/m²/yr.

The United Kingdom developed a roadmap for implementing zero carbon buildings by 2016/2019. In England the government has announced that from 2016 all new homes and from 2019 all new non-domestic buildings in England will be built to zero carbon standards. The process of nZEBs definition has been finished and built on the voluntary certification system "Code for Sustainable Homes (CSH)". From 2016 the carbon compliance limits for the building performance should be 10 kg CO2 (eq) /m²/year for detached houses or ~46 kWh/m2/year.

In Germany, the government carried out the project "Analysis of the revised EPBD" to research the possible nZEBs definition and determine the best solution [28], [29]. The analysis identified that the new buildings in 2020 will have an energy performance by 50% better than the buildings performance nowadays, i.e. according to the EnEV2009 standard. In addition, the actual legislation has to be changed for including the requirement for new buildings to comply with a nZEB standard.

A great variety of concepts, models and examples of highly energy-efficient or low energy buildings are available throughout Europe. Among these, the Passive House, 3-l house, and Energy Plus. In Germany, more than 13,000 passive houses have been built since the 1990s [30]. The German building codes have been strengthened five times over the past 35 years and the energy demand for space heating and domestic hot water has been reduced from 300 kWh/m2 to approximately 52.5–60 kWh/m2 primary energy [12].

In order to help MS to implement the nZEB concept, several projects have been developed. The Entranze Project intends to support the policy-making procedure by providing data, analysis and guidelines and connecting building experts from European research institutions and academia to national decision makers and key stakeholders [12]. The new legislative European environment seems to have motivated the private construction sector to take initiatives immediately.

Several national approaches to the nZEB application have been presented. They vary from zero carbon to explicit maximum primary energy values. Besides the primary energy indicator required by the new EPBD, many countries also intend to include a list of additional indicators, dealing with the building envelope and also with the building service system efficiency as well as the generated renewable energy. A gradual approach in form of a roadmap towards the 2020 goals is planned in most countries.

Romania, Poland and Bulgaria have already developed roadmaps for moving towards nZEBs. The estimated macro-economic benefits of implementing nZEBs between 2010 and 2015 are reported in Table 2 [31].

Table 2: Estimated benefits of nZEBs implementation in some MS, source [31].

	Poland	Romania	Bulgaria
CO2 savings (million t)	31	68	4.7-5.3
Energy savings (TWh)	92	40	15.3-17
Additional investments (million Euro)	240-365	82-130	38-69
New full time jobs	4100-6200	1390-2203	649-1180
Minimum requirements in 2015/2016			
Primary energy (KWh/m2/y)	70	100	60-70
Renewable share (%)	>20	>20	>20
CO2 emissions (KgCO2/m2/y)	<10	<10	<8
Minimum requirements in 2020			
Primary energy (KWh/m2/y)	30-50	30-50	30-50
Renewable share (%)	>40	>40	>40
CO2 emissions (KgCO2/m2/y)	<3-6	<3-7	<3-5

A database of Zero Energy Buildings throughout Europe has been created by IEA research program "Towards Net Zero Energy Solar Buildings" and it is still in progress [32]. The website testifies that built examples of nZEBs are diffusing in many countries. However, a considerable number of nZEBs project are in Germany, Denmark, Austria and Sweden.

Many available nZEBs use renewable supply Options nos. 0 and 1 in Table 1, i.e., the application of low energy building technologies and the use of renewable energy sources available. The most used renewable energy technologies are photovoltaic systems, solar heat collectors, air- and ground-source heat pumps.

A few nZEBs case studies are shown in Figure 5 and Table 3. Each case study is located in a different country, illustrating differences in climate, legislative context and building techniques.

Fig.5: nZEBs built examples in: a) Italy, b) Greece, and c) Austria.

Table 3: nZEBs built examples properties.

Location	Year of completion	Area (m2)	Energy demand (KWh/m2y)	Installed systems	U envelope, windows, roof (w/m2K)
Rovereto, TN (IT) (Fig.5a)	2011	211	6.83	Photovoltaic (6.45 KWp, 30 modules, 44 m2, grid connected) Solar heat collectors (4 collectors) Heat recovery ventilation (HRV) Ground source heat pump (GSHP) (2 vertical probes of 80 m each) Radiant heating	0.14 0.7 0.14
Agrià (GR) (Fig.5b)	2012	477	13	Solar heat collectors (300 l in each unit) Heat recovery ventilation (HRV)	0.21 1.32 0.066
Maria Enzersdorf (A) (Fig.5c)	2011	4100	14	Photovoltaic Heat recovery ventilation (HRV) Radiant heating Biomass district heating	0.097 1.00 0.101

Although the construction activity appears to slowly moving towards nZEBs, the vast majority of nZEBs are still demonstration projects, indicating the absence of a mass implementation of the concept.

6. Conclusions

According to the recast of the EU Directive on Energy Performance of Buildings (EPBD), by the end of 2020 all new buildings should be nearly zero energy buildings (nZEBs). As a consequence, the attention given to nZEBs increased consistently over the last decade. It is widely recognized that ZEBs have a great potential to decrease energy consumption and to increase at the same time the use of renewable energy. The reduction of the energy demand through energy efficient measures and the utilization of renewable energy sources to supply the remaining demand seem an agreed point towards the implementation of nZEBs in all the MS. However, a consensus about definitions and system boundaries appear far to be reached.

The level of energy efficiency, the inclusion of lighting and household electricity, as well as the renewable typology to be implemented are hard to be defined and approved.

The paper showed how many aspects still remain under discussion and interpretation (metric, period and types of energy included, renewable options, connection to the infrastructure, etc). It also underlined the urgency of a harmonized definition framework and a robust "zero" calculation methodology.

Only 16 Member States have published a national plan (12 in English) [33]. This might indicate that many MS do have problems to develop and implement suitable instruments and measures. Another reason could be that the deadline for the national plan was too tight as MS had to report on a complex nZEB plan only two years after the EPBD-recast [34].

The MS that did report have chosen very different forms of reporting, so that the national plans are not comparable. Therefore it is of primary importance to provide a reporting template for future reports to enable evaluating and cross-analysing the national plans.

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Nearly Zero Energy Building - towards a common definition

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Abstract

A binding roadmap and a definition of nearly zero energy buildings (nZEBs) is given in the Energy Performance of Buildings Directive (EPBD). Member States are asked to report ‘detailed application in practice of the definition’ and provide a roadmap towards nZEBs. The analysis of the applications in Member States [5] shows that the definitions of nZEBs are varying a lot (e.g. by the number of requirements set).

A coherent and common definition of nZEBs is needed:

- to be able to understand the content of the numerical indicator and the related requirements in different Member States;
- to guide industrials in the development of solutions and to give them the possibility showing the impact of the developed solution in a transparent manner at European level.

The European Commission asked CEN (mandate M480) to develop standards supporting the application of the recast EPBD in Member States.

This article shows and explains the first ideas of the CEN development for a common definition of nZEBs.

1. The challenge for the EU: Reduction of energy consumption (climate change) and of external energy supply dependency

As indicated in the Directive 2010/31/EU on Energy Performance of Buildings (EPBD), buildings account for 40 % of total energy consumption in the European Union. In its Green Paper "Towards a European Strategy for Energy Supply" the Commission highlighted that the European Union will become increasingly dependent on external energy sources. Based on current forecasts, if measures are not taken, import dependence will reach 70% in 2030, compared to 50% today .

Therefore the reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union’s energy dependency and greenhouse gas emissions.

2. Nearly zero- energy buildings (nZEBs) – a precise and binding roadmap, a huge challenge and an important market

The European Parliament and the Council of the European Union have adopted Directive 2010/31/EU EPBD which lays down requirements related to nearly zero- energy buildings (nZEBs) in article 9.

It is stated that Member States shall:

- set intermediate targets to improve energy performance of new buildings by 2015, preparing the implementation of nZEB;
- ensure that after 31 December 2018, new buildings occupied and owned by public authorities are nZEBs ;
- ensure that by 31 December 2020, all new buildings are nearly zero- energy buildings;

Furthermore Member States shall take measures such as setting targets in order to stimulate the transformation of buildings that are refurbished into nZEBs.

3. Definition of nZEBs in the EPBD

Article 2 of the EPBD states that a nZEB is a building that has a very high energy performance, which means that a very low amount of energy has to be required for a typical use of the building including energy used for heating, cooling, ventilation, hot water and lighting.

The high energy performance has to be determined in accordance with Annex I EPBD taking into account:

- indoor climatic conditions;
- thermal characteristics of the building;
- HVAC installation, hot water supply, built-in lighting installation;
- active solar systems and other systems based on energy from renewable sources;
- district or block heating and cooling systems.

The very low amount of energy required has to be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

The EPBD requires that a nearly zero-energy building is characterized by a numerical indicator of primary energy use expressed in kWh/m2 per year.

This definition is in line with the challenges facing the EU (reduction of energy consumption, climate change, use of energy from renewable sources) .

In article 4 the EPBD requires the setting of minimum energy performance requirement. The "added value" in the definition of nZEBs is the following:

- setting a priority between the reduction of the energy required and the use of energy from renewable sources;
- (implicit) setting requirements for additional information, such as the percentage of energy from renewable sources in the total energy consumption (see also article 11);
- setting the assessment perimeter of on-site and nearby;
- setting a numerical indicator as the ratio between the primary energy use and the area on a yearly basis.

The 'Action plan for energy efficiency: realizing the potential' identified the significant potential for cost-effective energy savings in the buildings sector. Defining a 'nearly zero' target indicates where, according to the EPBD, new European buildings should tend to.

4. Needed clarifications in the definition of nZEBs and their impact on the energy performance assessment

EPBD states that the definition of nearly zero energy buildings shall include a numerical indicator of primary energy use expressed by the ratio of the energy consumption and the building area. Hereafter the denominator and the numerator of the ration are discussed.

4.2. The denominator

The numerical indicator of nZEBs is a ratio. The denominator of the ratio is an area. The definition of the 'area' is not detailed in the Directive. The Directive mentions 'total useful area' in article 4.

The definition of the area has an important impact on the numerical indicator (e.g. difference up to 20 % between the choices of internal or external dimension).

To be able to understand and to analyze the numerical indicator a clear definition is needed. But this article mainly focuses on the numerator.

4.3. The numerator

Very low amount of energy required – need for a common and sound methodology

Article 3 of the EPBD requires that Member States shall apply a methodology for calculating the energy performance of buildings in accordance with the common general framework set out in Annex I.

European countries calculate the energy use and the total primary energy use by more or less complete, by more or less detailed methods. For example some countries use hourly methods and a holistic approach, whereas other countries use tabulated values to express the yearly energy efficiency of technical building systems. New technologies like on-site cogeneration units are not taken into account in all calculation methods. As the amount of energy required is depending on the calculation method, the results are variable and the contributions of some new technologies are not always estimated on a sound basis.

Renewable sources on-site or nearby – need for a definition

The EPBD Directive only indicates that the localization of energy sources or energy conversion to be taken into account are ‘on-site’ or ‘nearby’ but does not define both perimeters.

The definition of on-site and nearby has an important influence on the assessment of a nZEB. As all new and refurbished buildings shall be nZEBs, the definition impact also the development of technology and the choice of investments made by the building owner.

In order to increase the energy performance of his building, a building owner can decide to invest not only in the building itself, but also in the ‘nearby’ energy source (e.g. in a biomass boiler of a district heating plant where his building is connected to). In this case, enlarging the assessment perimeter will contribute to increase the use of energy from renewable sources, make the investments more cost efficient and open new possibilities for increasing energy performance.

Sometimes it is considered that a building owner cannot decide what is going on at the district heating level and therefore it should not be reflected in the building certificate. It is remembered that some of the district heating systems are owned by the connected building owners and that the choice of the building owner to choose for example a direct electrical heating systems is reflected in his certificate, even if he cannot influence the electrical power plant.

Covering the amount of energy required – need to precise the possibility of compensation

Another issue having a huge impact on the definition of nZEBs is the interpretation of how to cover the very low amount of energy required by the building. The energy required is covered by different energy carriers (e.g. gas, oil,).

There could be several possibilities, such as:

- one energy carrier could be compensated by another energy carrier (e.g. gas could by compensated by the PV electricity production on-site);
- one energy carrier can be only compensated by the same energy carrier produced on-site or nearby (e.g. gas by biogas, electricity by PV electricity);

In the last case the technology of nZEBs would be very strongly orientated to the use of electricity (e.g. heat pumps instead of condensing boilers), because the on-site production is mostly PV electricity, and it would have a huge impact on the European energy mix.

If it is allowed to compensate an energy carrier by another energy carrier then it has to be defined how to compensate it.

There could be several possibilities, such as:

- One to one compensation:
  In this case 1 kWh electricity could be compensated by 1kWh biogas, 1kWh gas by 1kWh PV electricity;
- Compensation based on the use the primary energy factors:
  In this case the primary energy factor for compensation needs to be defined.

In case of compensation between the energy carriers the time step of compensation (e.g. hourly, monthly, yearly) is also very important. If it is admitted that the energy required by the building in winter is compensated by the PV electricity production in summer, then the numerical indicator of nZEBs will completely change and impact the development of the related technology.

5. CEN proposal for a common and flexible frame - Mandate 480

To support Member States in the transposition of the Directive into national application, the Commission gave mandate to CEN to work out a set of standards. CEN completed the Directive with more detailed definitions and worked out transparent and unambiguous calculation procedures. The target was to set up a common and flexible methodology allowing the Member States to take into account national, regional or local characteristics within this common methodology.

Within this common structure Member States can set up their level of requirements according to their priorities (e.g. more focusing on the building envelope; more focusing on the total primary energy).

5.1. CEN standards related to the very low amount of energy required

Taking into account the experience of Member States in calculating the energy use of the building, CEN developed a complete set of standards taking into account especially new technologies.

These set of standards are focusing on the interactions between the technical building system and the building envelope, between the building services (e.g. lighting and cooling). In nZEB's these interactions, the possibility of the calculation method to take into account recovered losses and gains, become more and more important as the energy consumption is reducing.

Indoor climate (e.g. overheating) is also treated. Interaction and indoor climate are crucial topics by determining the 'very low' amount of energy required.

Other challenges to calculate the very low amount of energy required by the building in reference to the CEN method are: the usability of calculation methods, data collection and product characterization related to the system approach.

5.2. CEN definitions related to renewable sources on-site or nearby

'On-site'
CEN defines 'on-site' as the 'building and the parcel of land allocated to the building'. In case of building sites with multiple buildings, the parcel of land related to the assessed building has clearly to be defined. This is to avoid double counting of energy sources. The rationale for the definition of 'on-site' is the unique and strong link with building.

'Nearby'
CEN defines 'nearby' as 'Energy source which can be used only at local or district level'. This definition was estimated as wake and therefore completed by 'requires a dedicated equipment to be connected to the assessed building (e.g. district heating)'. The rationale for the definition of 'nearby' was the possibility to calculate a specific primary energy factor and to have still a specific link between the building and the energy source.

The difficulty with the definition of 'nearby' is that wood not growing on the parcel of land belonging to the building is excluded as renewable source covering the low amount of energy required by a nZEB. The discussion about the definition of 'nearby' is still on-going.

5.3. CEN proposal related to the possibility of compensation

The CEN proposal takes into account compensation between energy carriers at different time steps (hourly, monthly, yearly). The principle of compensation is the balance of delivered and exported energies weighted by primary energy factors at assessment boundary.

The balance at assessment boundary is also used to calculate the renewable energy ratio (RER). The RER is the ratio of the delivered renewable energies on the total delivered energy minus the total exported energy.

For more information see [1], [2], [3].

6. CEN proposal for a coherent assessment of nZEB – the CEN hurdle race

The EPBD set two requirements to define nZEBs (see chapter 3). The use of only one requirement, e.g. the numeric indicator of primary energy use, can be misleading because a high amount of energy required can be compensated by a low primary energy factor.

In addition the EPBD set several requirements:

- Article 4: Member States shall set minimum energy performance requirements for building elements having a significant impact on the energy performance of the building envelope;
- Article 8: Member States shall set system requirements in respect of the overall energy performance for the purpose of optimising the energy use of technical building systems.

CEN proposes to combine the different EPBD requirements in a coherent assessment of nZEBs. The proposed assessment methodology [1] goes step by step 'from the needs to the overall energy performance expressed in primary energy use'. Only if the requirement of each step is reached, then the building can be qualified at the end as 'nZEB'. This approach is comparable to a hurdle race.

1st hurdle: Energy needs

The first requirement is reflecting the performance of the building envelope (article 4 EPBD) characterised by the energy needs. The energy needs are based on local conditions and the designated function of the building. They take into account the quality of the building envelope (e.g. insulation, windows), the bioclimatic design (e.g. solar gains, natural lighting) and the indoor climatic conditions in order to avoid possible negative effects such as inadequate ventilation, hygrothermal problems. The energy needs are calculated with EN ISO 13790 [4].

2ndhurdle: Total primary energy use

The second requirement is reflecting the performance of the technical building systems (HVAC installation, hot water supply, built-in lighting installation) characterized by the energy use (article 8 EPBD).

Technical building systems are linked to an energy carrier (e.g. gaz boiler; auxiliary consumption). To add the different energy carriers in a coherent manner the second requirement is expressed in total primary energy. Default values for primary energy factors are given in the CEN standards [1]. The total primary energy use is calculated with prEN 15603 [1].

EPBD defines primary energy as energy from renewable and non- renewable sources. CEN has defined the related primary energy factors (PEF):

- non-renewable primary energy factor taking into account only non-renewable energy overheads of delivery to the point of use, excluding renewable energy overheads and primary energy components;
- renewable primary energy factor taking into account only renewable energy overheads of delivery to the point of use, excluding non-renewable energy overheads and primary energy components;
- total primary energy factor. The total PEF is the sum of the non-renewable primary energy factor and the renewable primary energy factor.

The total primary energy use is a coherent way for setting technical building system requirements (article 8 EPBD) because some systems (e.g. direct electrical emitters) have some of their systems losses outside the building assessment boundary (e.g. electricity generation). The total primary energy factor takes into account the losses outside the assessment boundary.

3rdhurdle: Non-renewable primary energy use without compensation between energy carriers

The third requirement is reflecting the contribution of energies from renewable sources (e.g. active solar systems and other systems based on energy from renewable sources, district or block heating and cooling systems) characterized by the non-renewable primary energy consumption. This third requirement does not take into account compensation between energy carriers for example by on-site PV production. The non-renewable primary energy use is calculated with prEN 15603 [1].

Arrival nZEBs: Numerical indicator of non-renewable primary energy use with compensation

Only at this stage the compensation between energy carriers is admitted.

The different hurdles are well identified in the CEN calculation procedure. By following the hurdle race negative side effects (e.g. as uncomfortable buildings) can be avoided. The numerical indicator of non-renewable primary energy is calculated with prEN 15603 [1].

7. Conclusions

The European Commission asked CEN (mandate M480) to develop standards supporting the application of the EPBD in Member States and to complete EPBD definitions where needed.

CEN completed the nZEB definition, worked out a common, clear, unambiguous assessment structure and the related standards to calculate the very low amount of energy required by nZEB. The common structure is flexible in order to take into account national, regional and regional choices.

CEN combined the definition of nZEBs and the different EPBD requirements in one assessment method (hurdle race). By following the hurdle race negative side effects (e.g. uncomfortable buildings) can be avoided.

Member States can set level of requirements according to their priorities within this common assessment structure.

EPBD nZEB requirement is a significant contribution to the EU's commitments (e.g. climate change) and a huge challenge for the EU building sector. A common, unambiguous definition of nZEBs and a transparent assessment method is needed to guide and motivate EU professionals in the development of adapted solutions.

European professional needs clear, unambiguous European rules and definitions.

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The GreenBuilding Programme Evaluation analysis 2010-2012

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Abstract

The goal of improving end-use energy efficiency and promoting the use of renewable energy sources is a key component of the EU energy and climate change policies, shared by all EU Member States. The European Commission contributes to this goal through a series of policy actions. Given the large share of energy consumption in buildings and the large cost effective energy saving potential, special attention has been dedicated to the building sector.

The GreenBuilding Programme launched in early 2006, is one of these actions, aimed at improving energy efficiency in private and public non-residential buildings, in Europe, on a voluntary basis.

Owners of existing as well as newly constructed buildings, meeting the GBP energy performance criteria, from different sectors are participating in the programme, e.g., public authorities with schools, hospitals, museums or libraries, companies from the service and industry sectors with office buildings, spa centres, hotels, etc.

The paper presents the GreenBuilding Programme results achieved in the period 2010 to 2012. The main analysis focuses on the energy saving achieved and the energy measures implemented in the participating building. On the basis of detailed data collected during the above period, the paper present additional analysis compared to the report 2006-2009 [1] .

From January 2010 to December 2012, 261 Partners have joined the Programme with 486 Buildings. The total savings achieved by the Partners in this period are 310.10 GWh/year. The average percentage of savings, from 2010 to 2012, amount to 40,58%, which is well above the GreenBuilding Programme requirements (25%).

Office buildings are the most represented building type among the Partner buildings and therefore also represent almost half of the total absolute savings (202.47 GWh/year). Among countries, the highest savings so far have been achieved in Germany and Sweden, together accounting for more than half of the savings (217.51 GWh/year).

There is a statistically significant relationship between the variable number of saving measures and percentage savings. The highest average savings are achieved when 3 measures are implemented (41%). Furthermore, the percentage savings depend also on the year of construction of the building, as shown by the end of the paper.

The present paper focuses mainly on the typology of the participating buildings, on the efficiency measures implemented (Envelope insulation, HVAC, lighting technology, renewable energy sources, etc.) and on the related savings achieved.

1. Introduction

According to the European Commissions (EC) Action Plan on Energy Efficiency from 2006, the building sector accounts for more than 40% of the final energy demand in Europe, therefore it represents an area where important improvements in energy efficiency could be realised. At the same time, improved energy efficiency of buildings constitutes one of the largest potentials for energy savings and thus reduction of CO2 emissions. Such savings would also improve the energy supply security and the EU's competitiveness, while creating jobs and raising the quality of life in buildings.

The GreenBuilding Programme (GBP) launched in early 2006, is one of these actions, aimed specifically at improving energy efficiency and expanding the integration of renewable energies in private and public non-residential buildings in Europe on a voluntary basis. It encourages owners of non-residential buildings to realise cost-effective measures which enhance the energy efficiency of their buildings in one or more equipment system.

The GBP is managed by the Joint Research Centre (JRC) of the European Commission, and it is complementary to the EU Energy Performance of Buildings Directive (EPBD). The Programme is operational in all 28 European Union (EU) Member States, European Economic Area (EEA) countries, Switzerland, Norway, accession countries as Iceland, Montenegro, Serbia, the Former Yugoslav Republic of Macedonia, Turkey, and in companies from other continents such as China.

To become a GBP Partner, building owners perform an energy audit of their existing buildings and formulate an action plan to improve energy efficiency. By applying to the GBP, potential Partners agree to reduce the primary energy demand of the building by at least 25% (if economically viable) and to report the results on the renovation measures. The energy consumption is measured prior to and after the renovation. For new construction, investors or building owners design a building using at least 25% less energy than requested by the building code in force at the time. The energy savings are calculated from modelled energy use.

Fourteen organisations from 13 European countries are supporting the implementation of the GBP in the national context; these organisations are called National Contact Points (NCP) and they assist building owners in this process by providing guidelines for energy saving renovation and website in the national language containing an inventory of best-practices. Other private and public organisations (Endorsers) may help potential Partners to join the programme. Besides reducing energy as well as operational costs, other reasons for building owners to join GBP are:

- Public recognition for the participating organisations
- Practical help from the NCP
- Public commitment to environmentally friendly behaviour
- Corporate Social Responsibility
- Reduction of CO2-emissions

Participation in the GBP for existing buildings starts with the submission of an action plan defining the scope and nature of the company's commitment. Based on an initial energy audit, the action plan must define the buildings in which energy efficiency measures will be undertaken as well as the energy services (heating, lighting, water heating, ventilation, air-conditioning, office equipment, etc.) and the specific measures to which the commitment applies. If the action plan is accepted by GreenBuilding, the company is granted Partner status. For new buildings, energy modelling and description of the building are needed to prove that the building's energy consumption is 25% below that specified in the building code. The GBP encourages its Partners to tap a large reservoir of profitable investments without the need for specific incentives from the public authorities. GBP investments use proven technology, products and services for which efficiency has been demonstrated. It is thereby considered to make good business sense for companies to join the GBP. [2]

GreenBuilding provides support to the Partners in the form of information resources and public recognition, such as media coverage in newspapers and magazines, presentation at fairs and conferences throughout Europe, a regular newsletter, and a brochure and a catalogue of success stories. The GBP plaque allows Partners to show their responsible entrepreneurship to their clients.

The present paper analyses the results of the GreenBuilding Programme achieved within the last three-year operation of the GBP. It focuses on the energy savings achieved and the energy efficiency measures implemented in the participating buildings.

2. Methods

Partners who join the GreenBuilding Programme with their buildings include a report to their application, in which they provide information on the level of achieved savings and a description of the efficiency measures through which they achieved the declared savings. These reports served as a basis for the analysis. The period under assessment is from 2010 to 2012.

The buildings are assessed as to the reported year of construction (and in this connection, whether the buildings are new or refurbished), floor area and prevalent use (building type) as there are many types of buildings. The following table (table 1) shows the main categories into which the buildings are categorised in order to allow for the analysis while capturing the prevalent uses of the building.

Table 1: Business categories (prevalent in case of multiple categories)

Building Category	Building subcategory
Cultural	Museums, churches, libraries
Education	From kindergarten to universities
Healthcare & Social Work	Hospitals, rehabilitation, day care centres, social care
Hotel & Accommodation	Hotels, Inns, Resorts, Mansions, Public housing
Institutional	Municipal halls, courts, penitentiaries, conference rooms
Logistic & Storage	Production halls, manufacturing buildings, workshops
Manufacturing & Industry	Storage, warehouses,
Offices	Buildings mainly for office use
Other	Other uses, Fire station, Social housing
Restaurants & Catering	Buildings comprising canteens and restaurants
Sports & Leisure	Spas, leisure centres, swimming pools, sport centres
Transport Infrastructure	Airports, train stations
Wholesale & Retail	Shops, supermarkets, Warehouses

The achieved energy savings are analysed as to their absolute levels (MWh/year) and in relative terms (% of the consumption). The achieved (or modelled) energy consumption is compared to the pre-refurbishment state for existing buildings or to the relevant legal requirement state for existing buildings or to the relevant legal requirements or conventional buildings for new buildings. The general characteristics of the buildings (building type and area, year of construction, country) are also taken into account.

The efficiency measures vary to a certain extent among Partners (given the different use, geographical area or year of construction). Nevertheless, based on the Partner's reports, the measures are categorised into six main areas which have been found to be the common denominator (Table 2).

The main categories (Building envelope, HVAC, Lighting, Renewable energy sources (RES), Control systems and Other) are in some cases further divided into subcategories to give a better picture of the measures applied. Within the general category HVAC, subcategory of Heating, combined heat and power generation (CHP), heat pumps and biomass boilers are earmarked (the last two could at the same time be categorised under RES). RES are further divided into solar panels and photovoltaic installation. From building envelope measures, summer heat protection is highlighted. The category "Other" mostly includes water saving systems, as well as efficient appliances or staff training.

Table 2: Types of measures

Category	Subcategory
HVAC	Reconstruction of heating system
	Heat Pumps
	Biomass/biogas boilers
	CHP
	Ventilation/Air-conditioning/Cooling
Building envelope	Building envelope
	Summer Heat protection
Lighting	Lighting
Renewable Energy Sources	Photovoltaic panels
	Solar panels
	Wind power technology
Control systems	Control systems
Other	Water saving systems, efficient appliances, staff training

All the data analysed in the paper is submitted by the Partners. There are some missing pieces of information in the Partner reports. Nevertheless, the missing items of information are relatively negligible – there are only two buildings for which no report has been provided. Yet, as there is no mandatory format of the reporting form in the participating countries, for some Partners only partial information is provided. The only section, however, where the number of provided sets of data is significantly lower is the information on economic characteristics of the projects, in which the sample consists of only 91 Partners.

The analysis is based on Partner's information. The JRC reviews the reports before granting the building and the organisation the status of GreenBuilding Partner. Nevertheless, the analysed data should be taken keeping this limitation in mind.

3. Results of the GreenBuilding Programme

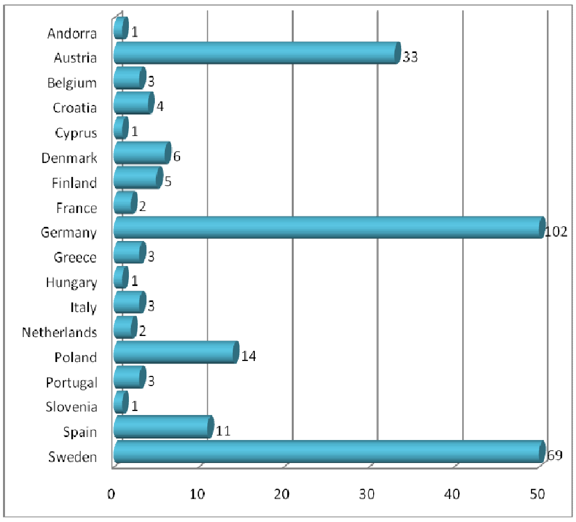
3.1. Number and type of participating buildings

At the end of December 2012, the total number of GBP Partners had reached 400, from which 238 just in the last three years. The total number of GBP certified buildings was 772, from which 486 only in the interval 2010 - 2012.1

1 The GBP Certificate is always granted to a specific building. Therefore, one GBP Partner can join the Programme with more than one building. Each of these buildings is assessed separately and receives the certificate on an individual basis.

During the first three years of operation of the Programme (2006-2009), 162 partners joined with 286 buildings. [3] Since then, the number of Partners and the number of Buildings more than doubled, reaching a total of 400 Partners with 772 certified Buildings. The partners come from 18 countries, of which 17 are EU member states. Geographically, both southern and northern countries are represented, and various climate zones from the mild temperate/mesothermal climates, to continental/microthermal climate and ending with polar climate type.

Fig. 1: Number of partners per country. *Note: The bars for Germany and Sweden have been shortened to make the other bars easier to read.*

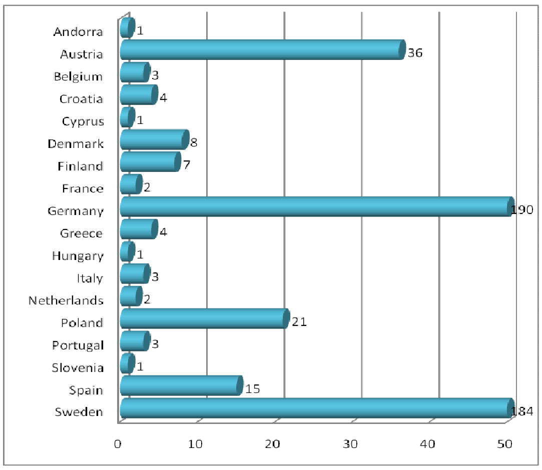


Te paper is analysing the detailed data collected during 2012-2012 from owners of non-residential buildings.

In this periode we received a large number of already existing edifices, recently refourbished, like the Carlston Fortress, built in 1658 on Marstrand island in Sweden, as well as new modern buildings like the UN City Campus 1, built in 2010 in Copenhagen, Denmark.

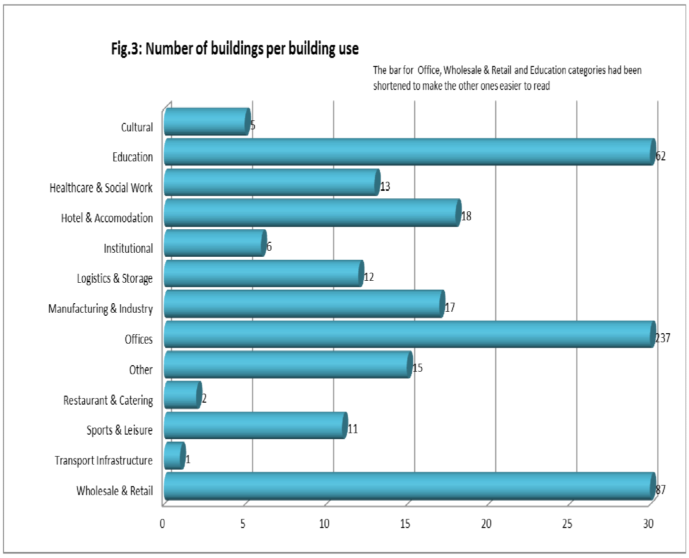
When looking at the graphic representation in Fig. 1, we can see that the highest number of GBP Partners come from Germany (102), folowed by Sweden (69). Austria has 33 partners and Poland 14. From non-EU countries, there is one Partnes from Andora. A few international companies, such as Skanska and Siemens, have joined the GBP in different countries.

Fig. 2: **Number of buildings per country.** *Note: The bars for Germany and Sweden have been shortened to make the other bars easier to read.*



The repartition of buildings per country is illustrated in Fig. 2. Here we can see that the higher number of buildings registered is in Germany (190) with approx. 2 buildings per Partner on average, followed by Sweden with 184 buildings (more than 2 buildings per Partner). In most countries though, the number of buildings to large extent reflects the number of Partners (Fig. 2).

Almost 49% (237 out of 486) of the buildings are offices (Fig. 3)2. The second largest group of buildings is wholesale and retail buildings (17.9 % of the GBP buildings). These include shops, supermarkets and warehouses. The education buildings (13%) comprise kindergartens, primary schools, high schools and universities. Hotel & Accommodation buildings and Manufacturing & Industry are represented by 18 respectively 17 buildings.



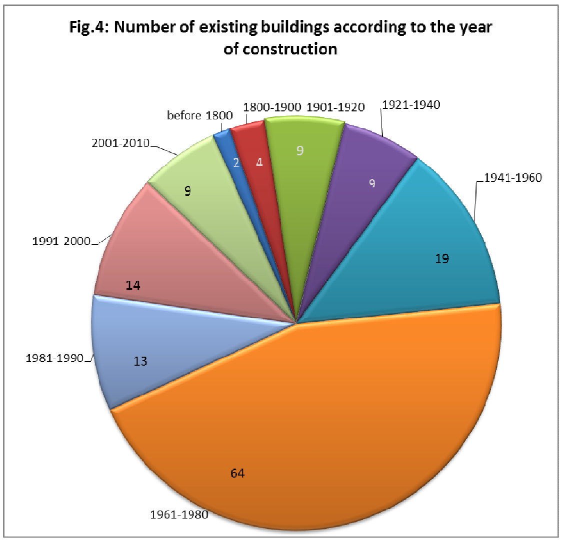
Among Other buildings (15 out of 486), there are garages and social housing. Healthcare & Social work, Logistic & Storage and Sports and Leisure are all represented by 13, 12 respectively 11 buildings while Institutional and Cultural by 6 and 5 buildings. Restaurant & Catering is represented by only 2 buildings and Transport Infrastructure by only 1 building - Landvetter Resecentrum which is a bus terminal adjacent to the highway bus stops.

The average area of the Partner buildings is 10,285 m2. However, the median of the sample is nearly half of the average – 5,354 m2 – meaning that 50% of the buildings are actually smaller than 5,354 m2. The sample is to a large extent skewed by office buildings. The smallest building only has 196 m2 and is newly built in 2005 in Balingen, Germany. Named "Neubau Niederlassung Balingen" is a one-store office building; a branch office of the company with a capacity of about 7-8 workplaces. The largest building of the GBP has 250 727 m2, is named "Westegate Büro-und Geschäftsgebäude" and is one of the refurbished office buildings in Koln, Germany.

Table 3: Existing buildings according to the year of construction

Year Range	Nr. on existing buildings
before 1800	2
1800-1900	4
1901-1920	9
1921-1940	9
1941-1960	19
1961-1980	64
1981-1990	13
1991-2000	14
2001-2010	9
N/A	67

Out of 486 buildings, there are 275 new buildings and 211 existing, refurbished buildings. Among hotel and restaurant, manufacturing and industry, and sports & leisure, refurbished buildings prevail. Conversely, there are far more registered new commercial centres, industry buildings and leisure facilities. Among the office buildings, there are 120 new buildings and 117 existing, refurbished buildings.



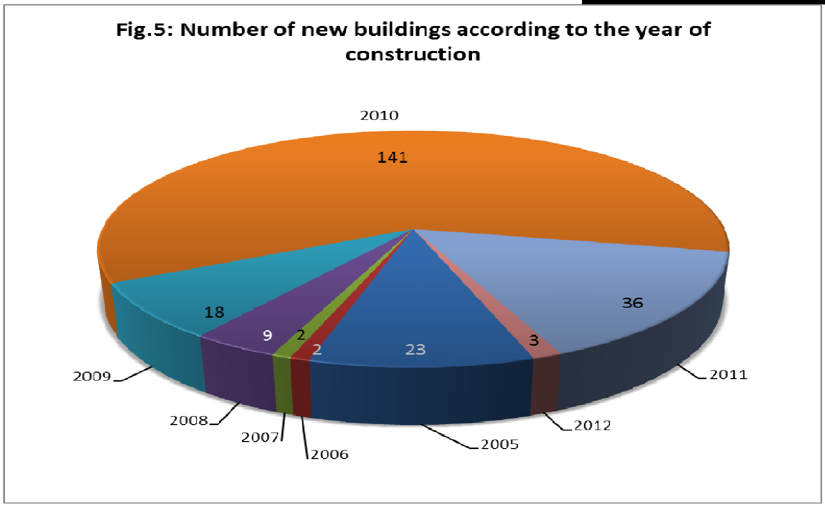
Most of the existing buildings were built between 1961 and 1980. The oldest building of the GBP 2010-2012 is a church in Gothenburg, Sweden, built in the 13th century. It is named Bergums Kyrka and belongs to Svenska Kyrkan I Göteborg partner. Another 5 buildings were built before 1900 (Table 3), while the newest refurbished building was constructed in 2010.[3]

When looking at the new building sample, we can see that these edifices were raised between 2005 and 2012 (Fig. 5). This means that the new buildings almost overlap the existing, already refurbished buildings. In absolute terms, most of the Partner buildings were finished in 2010 (141 Partner buildings out of 275 where this information was available), followed by constructions finished in 2011 (36 Partner buildings) and in 2005 (23 Partner buildings).

Table 4: Refurbished buildings according to the year of construction

Year built	Number of new buildings
2005	23
2006	2
2007	2
2008	9
2009	18
2010	141
2011	36
2012	3
N/A	41

3.2 Energy savings



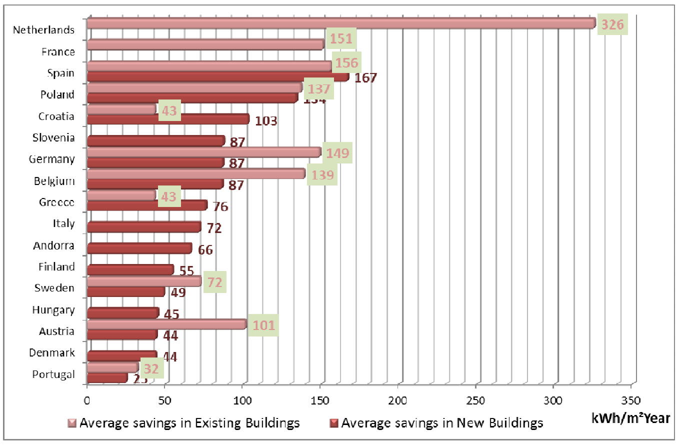
The GBP Partners usually report their savings in two ways: either as absolute annual savings or as kWh per m2 and year. In some case, both sets of data are reported. In the case of relative savings (%) it is not important which method of reporting is used. However, if we are to analyse the absolute savings, in the case of the latter method (reporting kWh/m2y) calculation is necessary.

Total savings of the GBP to date (GBP Partners until the end of 2012) have amounted to 614 GWh/year. The savings may have been underestimated. There are two reasons for this. Firstly, these savings have often been only estimated savings (e.g., for new buildings). And, as reported by some

3 It must be noted though that these are the years of original construction. In many cases, the buildings were of course reconstructed several times, or some parts of the buildings were added. This was however disregarded in the present analysis.

Partners, the verified savings tend to be even higher than the calculated levels. Secondly, there were 74 GBP Partner buildings for which no data on absolute energy savings were available (approx. 15% of the GBP buildings).

Fig. 6: Average of total savings per country



When looking at the representation of savings for all the buildings in GreenBuilding Programme 2010-2012, we can see that the amount of savings after refurbishment in existing buildings is much more important than the quantity of energy saved in new buildings relative to the reference value required by the building standard.

The maximum absolute savings were achieved in Germany – more than 138 GWh/year, Germany being also the first in terms of number of Partner buildings. Sweden follows with total savings of 79 GWh/year, Poland being the third with 45.85 GWh/year. When we relate the savings to the number of Partner buildings in these three countries, then the average savings per building are 727.42 MWh/year in Germany 429.74 MWh/year in Sweden and 2 GWh/year in Poland. This reveals that both in Germany and Sweden a larger but fewer projects prevail, whereas in Poland it concerns a great number of relatively smaller projects.

With regard to individual projects, the maximum absolute savings were achieved in one refurbished office building, in Koln, Germany, named "Westegate Büro-und Geschäftsgebäude". For this edifice, the maximum reference value for primary energy demand, estimated before constructing the edifice, was 243.2 kWh/m2y, whereas the office building achieved the primary energy demand in final status of only 166.6 kWh/m2y. That means 31.5% less energy consumption than required for the "Westegate Büro-und Geschäftsgebäude" office building. In absolute terms, it gives a saving of 19.2GWh/year.

In total there were only 325 Partner buildings, that reported on the percentage savings out of the total 447 Partner buildings in 2010-2012. These 325 buildings achieved more than 30% savings. The average achieved savings are 40.59%, the median is 37.08%. The maximum achieved savings on an individual basis were more than 91% (91.26%).[4] There are 10 buildings in which primary energy savings of more than 80% have been achieved. In seven cases, the measures included the building envelope and reconstruction of the cooling/ventilation system; in five cases efficient lighting was installed and in four cases the measures included reconstruction of heating systems.

When it comes to building type, the average percentage savings range from 55.76% in cultural centres to 35.79% in Manufacturing & Industry. The relative savings in offices, the most important building type as regards the total savings and total number of buildings, averages 38.29%.

4 It is a new building, thus the savings mean comparison with the respective legal requirements.

3.3.Specific energy demand in office buildings

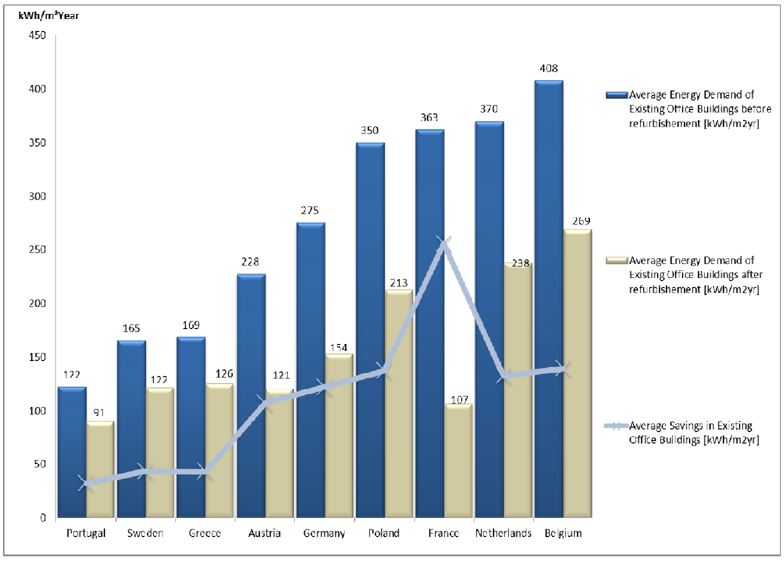
One of the most important indicators of efficiency with respect to buildings is the primary energy demand per m2 and year (kWh/m2year). At the same time, both building regulations for new buildings and the demand as such largely depend on the building type for specific energy demand analysis. Office buildings are the most frequent building type in the GBP and thus offer the largest sample for analysis. In office buildings, energy consumption related to kWh/m2year is the most predictable and has been analysed in other studies.[4] Office buildings (together with wholesale and retail stores) account for the highest share of energy consumption among non-residential buildings. [5]

The sample consists of office buildings, of which there are existing buildings and new buildings. The following analysis is divided according to this characteristic.

3.3.1 Existing buildings

The average pre-refurbishment primary energy demand per m2 of existing office buildings was 222.92 kWh/ m2 y. The lowest value was only 28.2 kWh/ m2y. The maximum demand before refurbishment reached 1113.66 kWh/ m2y. The highest specific primary energy demand after refurbishment was 826.11 kWh/m2y, whereas the minimum value reached only 8 kWh/ m2y.

Fig. 7: Average savings for existing office buildings



On average, the energy efficiency measures in refurbished buildings brought a decrease in the specific consumption of 95.50 kWh/m2y. The highest difference between the specific primary energy demand before and after refurbishment was 844 kWh/ m2y (from 1742 to 898 kWh/ m2 y) for a building in Germany. The lowest absolute difference reached 7.6 kWh/ m2y (from 28.2 to 20.6, which means savings of 26.95%).

The building energy consumption in existing buildings seems on average the lowest in Portugal – approx. 91 kWh/m2y (Fig. 7). Conversely, the highest consumption of conventional buildings is observed in Belgium, Netherlands, France, Poland, Germany and Austria, (over 200 kWh/ m2y), thus also offering the highest potential for savings. This potential is clearly shown in the case of France, where the average energy consumption after refurbishment decreased more than trice (from 363 kWh/ m2y to 107 kWh/ m2y). The existing office buildings in Sweden already tend to have a relatively lower specific energy demand (an average of 122 kWh/ m2y). Nevertheless, the average difference between the values before and after refurbishment is 43 kWh/ m2 y, still 26% of the original primary energy demands.

3.3.2 New buildings

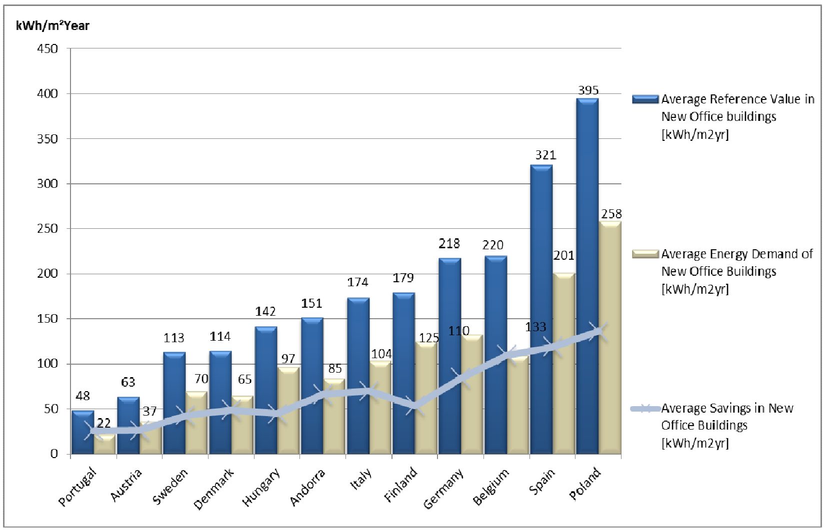
Fig. 8 depicts the increase in efficiency of newly constructed office buildings in the GBP. The reference values of the new buildings mean the building standards in force in the respective year to which the primary energy demand of the newly constructed buildings is compared, or it can be the level of consumption in reference with "conventional" newly constructed buildings in the country.

It is important to bear in mind that the values to which the new buildings are compared are not in every case representative of the current energy code requirements in those countries. Nevertheless, some patterns can be observed. The toughest requirements for GBP Partner buildings are in Portugal, Austria and Sweden. In Portugal the average primary energy consumption to which the newly constructed buildings relate is lower than 50 kWh/m2y; however, there was only one building in the sample. The average reference requirements in Austria are 63 kWh/m2y and 113 kWh/m2y in Sweden. The average specific primary energy consumption to which the new buildings are compared is 201.18 kWh/ m2y.

The lowest reference value is a legal requirement for passive houses: 28.2 kWh/ m2 y.

The maximum absolute difference reached between the energy code requirement and the real energy demand of the building was 520.72 kWh/ m2 y (49.84 kWh/ m2 y instead of 570.56 kWh/ m2 y, which is the reference national standard).

Fig. 8: Average savings for newly built office buildings



On average, the new Partner buildings consume 80.76 kWh/ m2y less than the respective national standards. The smallest achieved difference is of only 7.6 kWh/m2y. However, the approximately 7.6 kWh/m2y means 26.95% lower consumption even compared to the tough passive house standards. The relative savings in new office buildings average 38.05%, thus being below the overall average (40.59%).

3.4. Energy efficiency measures

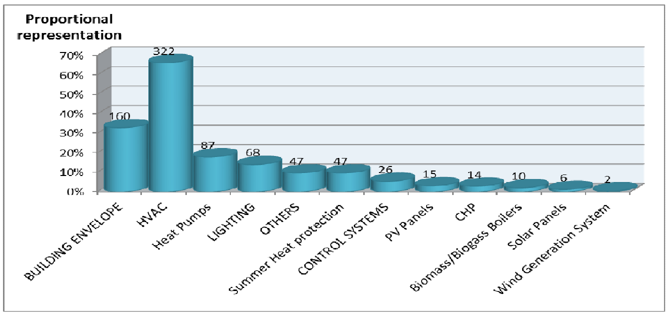
The energy efficiency measures are what makes the energy efficiency improvement (or energy savings) possible. Out of the total of 486 Partner buildings, 425 of them (87.44%) have reported on the implemented measures.

Fig. 9 depicts the main measures in terms of their proportional representation in the projects. The graph follows the (sub)categories set up in Table 2 above. The percentage values mean the share of Partner buildings in which the given measure was implemented.

The GBP Partners most often choose heating as their main target for efficiency measures. In Fig. 9, the reconstruction of the heating system (63.99% of buildings) entails reconstruction or dealing with the distribution systems within the building, use of district heating and/or conversion from one fuel type to another (not to biomass, but usually from oil to natural gas).

Additionally, depicted separately in Fig. 9, heat pumps have been used for heating in 25.31% of the Partner buildings. Where specified, these were universally geothermal heat pumps. In 3.09% of the Partner buildings, fossil fuel boilers have been replaced with biomass boilers. In one case, the boiler burns biogas.

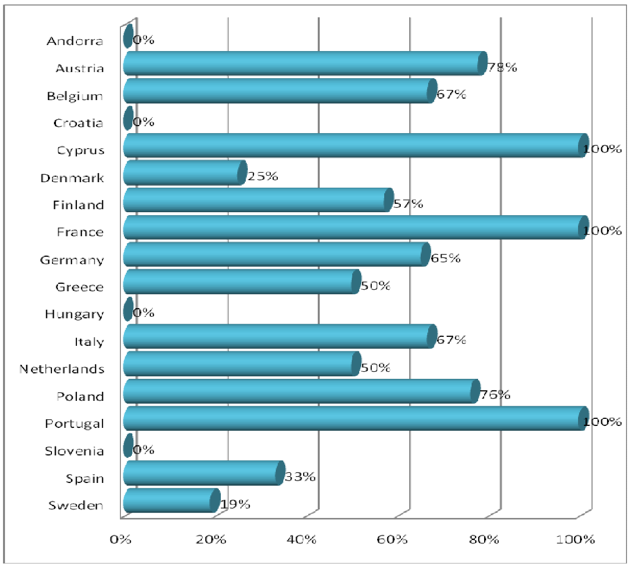
Fig. 9: Measures implemented in buildings



Combined heat and power generation (CHP) was used in 3.5% of the buildings (some buildings are also connected to district heating from CHP). Altogether, heating systems have been upgraded or dealt with in 56% of the cases.

More than 50% of the Partner buildings (51.23%) have focused on the ventilation/air conditioning and cooling systems. The measures mostly concern the heat recovery, replacement and proper dimensioning of pumps and fans (frequency transformers), resizing of the ducts or the overall system optimisation (zone regulation, optimisation of operation time, reduction of flow rates).

Fig. 10: ***Measures in building envelope per country***



The building envelope represents further significant potential for savings. The Partners have included it in the main measures in 46.70% of the cases. Yet, the scope of the improvements of the envelope systems differs to a large extent. It ranges from total insulation of the building, including the whole building envelope (roof, facade, ground and windows), to only featuring some parts of the envelope (such as better glazing or low u-values of the facade). Specifically, the buildings are equipped with summer heat protection (16.26%), which basically means external shading devices to protect the building from excessive summer heat gains. The shading devices tend to be movable electronically controlled and automated. There were several cases in which vegetation was used as a natural shading and air temperature reducing instrument. Lighting does not usually represent the highest portion of total energy consumption.5 However, lighting also represents one of the most easily achievable energy efficiency improvements, usually with very short payback times.6 That is why 26.33% of the GBP Partners have included lighting upgrading among the efficiency measures. The measures mostly entail the use of more efficient lighting (compact fluorescent lamps, efficient fluorescent tubes, electronic ballasts, LED lights). To add more savings, lighting is managed through motion/occupancy detectors, daylight sensors or through localised lighting.

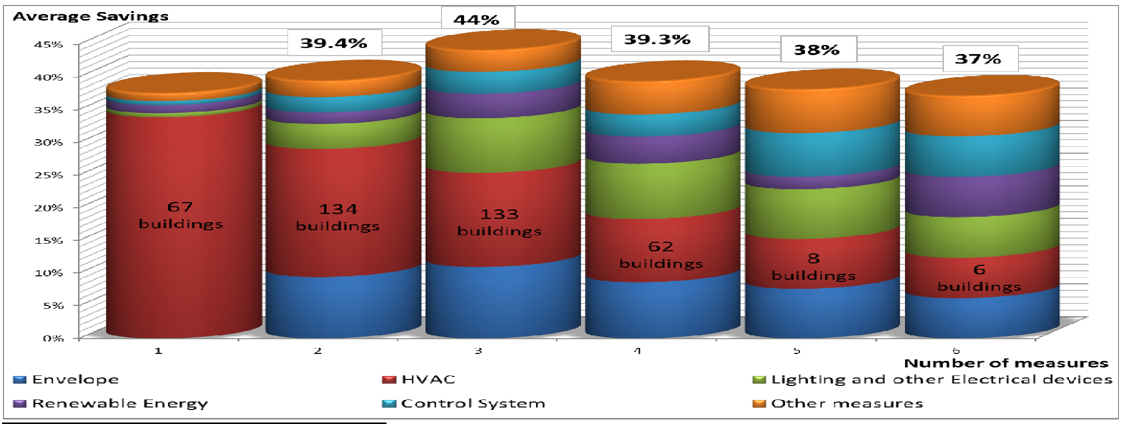
The Partners frequently install building energy management and control systems (14.6% of the cases). The systems (the term often used is Building Energy Management System, BEMS) control and monitor all the building's above-mentioned equipment, such as HVAC or lighting.7 The control systems also help in monitoring and evaluation of the energy consumption of the buildings, which provides a basis for further energy savings.

Other measures (19.54%) included water saving systems, activities to raise staff awareness and purchase of energy efficient appliances (mostly office equipment). The water saving system was often used in leisure centres and hotels, which include spas and swimming pools, but also in hospitals, where the use of sanitary hot water is high. The systems include use of rainwater, hot water recovery systems and low-flow taps.

Almost 5% of the buildings have installed a photovoltaic system or solar panels. The installed powers of the PV systems differ greatly. They range from small systems of 4–5 kWp to tens of kWp.

Two of the GBP Buildings have implemented Wind Power Generation Systems. A Fastighets AB Briggen property, Grusbacken - office building located in Helsingborg, Sweden - is a new edifice built after 2010 with high demands on energy efficiency. Also, a small restaurant built in 1980 and renovated in 2011, located in Amsterdam, Netherlands is now equiped with a wind turbine having the power of 2.5 kW.

Fig. 11: Average savings (%) per number of implemented group-measures



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5 For instance, as to [6] lighting represents approx. 11% of energy consumption in the tertiary sector (and 21% of tertiary electricity consumption), five times less than, e.g., space heating.

6 Similarly to GBP there is also the GreenLight Programme, which is a voluntary programme focused specifically on lighting.

7 The building management system can be further used to control security or fire systems.

ement 3.11 measures per building on average. The relation between the number of measures and relative savings in percentage is shown in Fig. 11. The numbers on top of the columns represent the number of buildings in which the respective number of measures was implemented.8 In respect to the average number of measures, Figure 11 shows that in most buildings three to four measures have been implemented.

There is a statistically significant relationship between the variable number of saving measures and percentage savings. The highest average savings are achieved when 3 measures are implemented (41%).

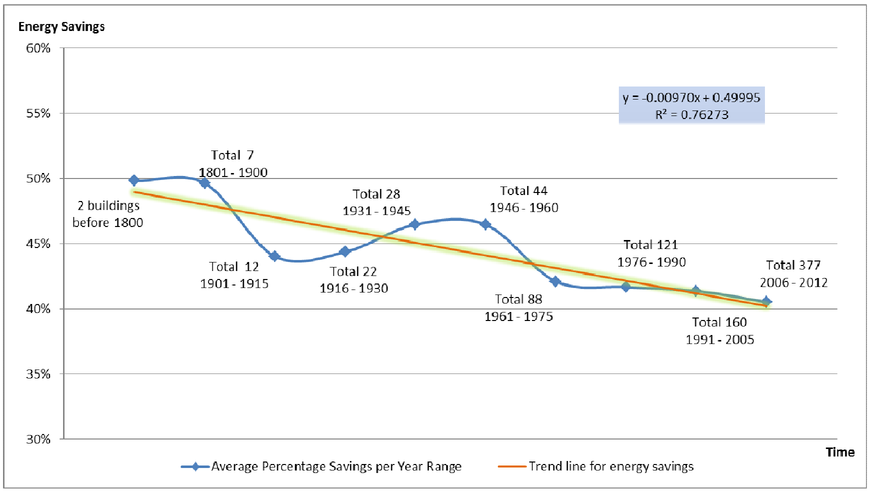
The most frequent combination of measures is Envelope+HVAC+Lighting (45% savings), followed by Envelope+HVAC+RES which redouces the Primary Energy Consumption at 50%.

The most frequent category of measures is HVAC, implemented in 66% of buildings. The second most implemented category is Building Envelope, implemented in 33% of cases. The combinations therefore closely follow the distribution of measures presented in Fig. 8.

Furthermore, the percentage savings depend also on the year of construction of the buildings. For the edifices built before 1900, nearly 50% of savings have been registered, while for the ones built after 1975 the savings decrease down to 42%, reaching 40% for the new buildings.

Therefore, from the analysed data, it is possible to conclude that the older the building, the higher the potential for savings.

Fig. 12: ***Average percentage savings according to the year of construction***



The case examples among the Green Building Partners show that primary energy consumption even in historical buildings can go far beyond the respective current building requirements and such reconstruction are economically efficient.

The trend line represents the long-term evolution in relative energy savings over, on average the last 100 years. Furthermore, the R-squared value on the chart indicates how well the data points fit the trend line. Since we know that the error is minimum when the R-squared takes value 1, which happens only when the trend line completely overlap the data points. Therefore, we remark that in the analysed situation, the value of 0.76 for the R-squared indicator shows that the trend line and the savings evolution during time have a good correlation.

[8] The "number of measures" means how many measures, structured as the main categories in Table 2, were implemented in the respective building.

3.5. Economic aspects of selected projects

The economic effectiveness of the projects is one of the prerequisites to become a GreenBuilding Partner and only a few Partners have reported on this. The economic aspects of the GreenBuilding Programme buildings could therefore be evaluated only to a limited extent.

Only a small fraction of Partners (91, meaning more than 18% of the Partner buildings) reported on the financial features of the energy efficiency investment. The main conclusions from their reporting are shown in Table 5.

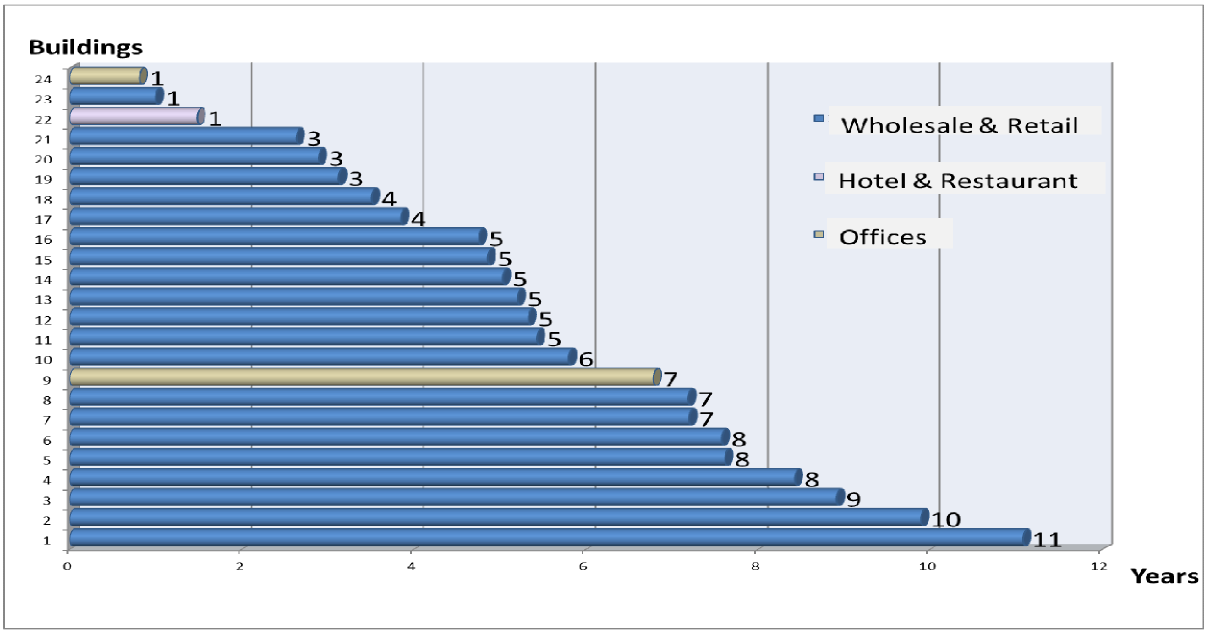
Table 5: Economic aspects of the GreenBuilding partner-edifice

Cost of investment [EUR]	Financial savings [EUR/Year]	NPV [EUR/Year]	Payback time [years]	Average savings [MWh/year]
141,762	85,220	22,145	5.41	197.73

Only 24 partners have reported on both the cost of investment and yearly savings, therefore the economic aspects of the Programe could be evaluated only to a limited extent.

In the case of new buildings, only additional costs for the energy efficient measures were included. When looking at the payback times of the investments, the numbers vary greatly (Fig. 13).

Fig. 13: ***Average Compound Payback Time***



The main conclussions from their reporting are shown in the table 5 comprising the average savings and average values for the economic indicators Cost of investment, Yearly Cost of Savings, Net Present Value and Payback time.

Analyzing the Investment Costs and assuming the discount rate of 5% and lifetime of 15 years for the measures, we obtain that the cost of 1 kWh/year saved was 0.71 euro.

The relation between Energy Savings and Financial Savings is that 1MWh saved correspond to 210 EUR of yearly financial savings in the sample.

When looking at the Payback time of the investment, we can see that the average compound payback time of 5.7 years is verry close to the median 5.33 years.

Some Partners set a low payback time (of less than three to four years) as a requirement for the energy efficiency measures and adapted the measures accordingly (implementing less costly measures with a short payback time, such as, e.g., lighting).

4. Conclusions

Within the last three-year operation of the GreenBuilding Programme, a total of 261 Partners have joined with 486 Partner buildings. The total savings achieved by the Partners are 310.10 GWh/year. In 2020, the savings will have accumulated to almost 2 TWh. On an individual basis, the maximum savings per project were 19.2 GWh/year (6.2% of the overall savings).

Office buildings are the most represented building type among the Partner buildings and therefore also represent almost half of the total absolute savings (202.47 GWh/year). Among countries, the highest savings so far have been achieved in Germany and Sweden, together accounting for more than half of the savings (217.51 GWh/year). The average percentage savings amount to 40.59%, which is well above the GreenBuilding Programme requirements (25%). The highest average relative savings have been achieved in cultural and restaurant & catering buildings (55%).

There is a statistically significant relationship between the variable number of saving measures and percentage savings. The highest average savings are achieved when 3 measures are implemented (41%).

Furthermore, the percentage savings depend also on the year of construction of the building, 50% savings for the buildings constructed before 1920, 50-45% for the buildings erected in 1920-1980 and the percentage decreases down to 40-30% for the new buildings, constructed after 2010. Therefore, from the analysed data it is possible to conclude that the older the building, the higher the potential for savings.

The case examples among the GreenBuilding Partners show that primary energy consumption even in historical buildings can go far beyond the respective (current) building requirements and such reconstructions are economically efficient.

Office buildings are the most frequent building type in the GBP and thus offer the largest sample for analysis. In the refurbished office buildings the average decrease in the specific primary energy demand was 83.37kWh/m2y. The analysis of GBP office buildings shows that large potential for savings exists where the original consumption is high; however, this potential does not seem to be fully utilised in all cases. On the other hand, even when the original energy consumption is relatively low, the potential for savings remains significant (tens of %).

On average, the new office buildings consume 80.76 kWh/m2 y less than respective building codes in force. The studied cases show that the Partner buildings can obtain energy consumption far below the reference standards (while respecting the economic efficiency of the projects) and even below the passive house standards.

In most of the GBP buildings, to achieve the above savings more than one energy efficiency measure has been implemented. Most often, it is a combination of three measures, and the highest average percentage savings were achieved through a combination of three to four measures. Most frequently, these entailed heating (63.79% of the buildings), air-conditioning and ventilation (51.03%), building envelope (35.80%) and lighting (26.34%). The reasons for implementing a number of measures at once are economic effectiveness as well as design needs. If not done at once, it may leave some of the measures unimplemented as there may not remain sufficient potential for savings.

The use of sun (photovoltaic and solar panel installations) is much more prevalent among GBP Partners from southern European countries. Also the wind is used in two buildings in Sweden and Netherlands. However, the focus on building envelope (and heating) is common to most projects without relation to geographical location.

Economic effectiveness is a prerequisite for joining the GreenBuilding Programme, all of the projects are assumed to be economically viable. This is one of the reasons why the Partners have rarely reported on the economic features of the projects.

The GreenBuilding Programme has been successful over its seven-year operation. The number of Partners is growing steadily. The aim now is to promote these good practice examples to a wider public.

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Intelligent Efficiency: Improvement Measures and Investment Analysis

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Abstract

Smart buildings utilize sensors, controls and analytics to improve energy efficiency, lower operating costs, and improve asset reliability. This paper catalogs an extensive set of 58 advanced monitoring, control and information management efficiency measures and describes a framework for evaluating the cost, energy savings, operational savings and return on investment for each measure. Application of the framework is demonstrated through a retrofit example of a typical 30+ year old commercial office building located in Arlington, VA. The retrofit example includes a collection of measures producing energy savings of over 40%, maintenance savings of 10%, with a positive net present value in a reference office building. Ninety percent of the efficiency gains and maintenance savings in our reference building come from a group of just 16 measures that improve single systems with multiple pieces of equipment in them, which we define as a level 2 level of influence in the building. These 16 measures are spread across a variety of sub-system categories including the chiller plant, boiler plant, air handling/terminal unit, plug load and lighting. The framework can be extended to include additional monitoring, control and information management measures and alternative local energy and labor costs in its analysis.

Introduction

Modern buildings are not just made of brick, mortar and machinery. Increasingly, buildings are measured by their intelligence – by the technologies that keep occupants comfortable and productive, save energy and money, reduce greenhouse gas emissions, and more. Intelligent technologies have potential to transform how buildings are operated and maintained and to foster a more sustainable future.

Intelligent buildings use sensors, controls and analytics to improve energy efficiency, lower operating costs, and improve asset reliability. Building intelligence can be improved across many building systems, including the chiller plant, cooling tower, boiler plant, air handling/terminal units, lighting and plug loads.

Investments in in building intelligence can be very attractive financially. But, building owners need a methodology to review intelligent technology options and decide which investments make the most economic sense for a given building in a given place. This paper outlines a sound methodology for doing exactly that.

Decisions about investments in improved building intelligence should be based on an analysis of both the simple payback and the net present value (NPV) of each measure. Calculations involving simple payback and percent energy savings can help decision-makers assess and prioritize among building intelligence investment options. The analysis then can extend to bundling the technology improvements into packages of measures based on simple payback, and to determining the cumulative NPV of each group.

This paper demonstrates a method of evaluating investment for 58 building intelligence measures using simple payback, NPV, and a curve showing the marginal cost per annual kWh saved for different groups of measures. It applies the methodology to a reference building – a typical 30+ year-old commercial office building in Arlington, VA, whose owners are planning a retrofit to improve the building's performance.

Simple Payback and NPV as a Framework for Evaluating Building Intelligence Measures

As with any investment, the decision to invest in improving the intelligence of a building should be based on sound financial criteria[1]. The investment should meet the building owner's payback criteria, and the net present value of that investment should be positive.

A detailed summary of assumptions of this framework can be found in Appendix 1. Details regarding the sources of data and assumptions regarding savings and costs of each measure can be found in Appendix 2. A basic summary of the calculations involved is:

Implementation Cost = equipment costs + labor costs

Total Cost Savings = Electrical Energy Cost Savings + Thermal Energy Cost Savings + Maintenance Savings

$$\text{Simple Payback} = \frac{\text{Implementation Cost}}{\text{Total Cost Savings}}$$

Net Present Value (NPV) is the present value of 15 years of future energy and maintenance savings, minus the implementation cost, assuming an 8 percent interest rate for a competing investment. A positive NPV indicates that the investment in building intelligence has a higher return than the competing investment.

By using this framework a company can gain good directional information on the types of building intelligence to invest in and a means of setting priorities among these investments. This framework can be extended to include additional monitoring, control and information management measures. It can also be adjusted for other types of buildings and varying local energy and labor costs.

A key limitation of this framework is that we did not model the dependencies between different intelligence measures. Each measure was evaluated independently from the others. For example, the measure called "Computer Monitor Brightness Control" would be less effective if the measure called "Computer Sleep Settings" is implemented.

Reference Building

A reference building is used to demonstrate how simple payback and NPV can be used to make decisions about investments in building intelligence. Cost savings are calculated from baseline energy used in this building. The building was selected as a representative example in the Whitestone Facility series of construction references[2].

The reference building used in this document is a typical office building – a 23,000 square-meter (250,000 square-foot) concrete office tower with 15 floors, 18,500 square-meters (200,000 square-feet) of pavement for parking and access, and 14,000 square-meters (150,000 square-feet) of grounds. It was built before 1980.

The building is assumed to be occupied 15 hours a day. The total occupancy is 2,250 people. The mean hours of operation are 50 hours per week (Bank/Financial)[3].

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[1] CABA IS 2004-20, Life Cycle Costing of Automation Controls for Intelligent and Integrated Facilities, 4/2004
CABA IS 2005-30, CABA Consulting Report on Life-Cycle Costs, 4/2004

[2] Whitestone Facility Maintenance and Repair Cost Reference 2012 - 2013, Whitestone Research
Whitestone Facility Operations Cost Reference 2012 - 2013, North American Edition, Whitestone Research

[3] Commercial Buildings Energy Consumption Survey – Commercial Buildings, US Energy Information Agency, 2010

The HVAC cooling source is chilled water, while the heating source is a gas boiler. There is a forced air multi-zone HVAC distribution system. The building is assumed to contain a building automation system (BAS). The energy consumed is 4.8 kBtu/sq-m/year (52 kBtu/sq-ft/year)[4]. The energy costs are $0.14/sq-m/year ($1.54/sq-ft/year), for a total spend of $384,924[5].

The HVAC equipment in this building is assumed to be one to ten years old to ensure that the equipment is not near its end of life. The annual maintenance spend for the HVAC equipment is $105,000. The HVAC Equipment[6] consists of:

Equipment	Quantity	Equipment	Quantity
Circulation pump, 75 hp, hot water	4	Expansion tank, 950 liter (250-gallon)	2
Gas boiler, 950 liter (250-gallon)	3	Centrifugal chiller, 250-ton	3
Cooling tower, 250-ton	4	Cooling tower, 500- ton	1
Air handler, multizone, 15,000 cfm	30	Roof-mounted exhaust fan, 10,000 cfm	2
Circulation pump, 25 hp	8	VAV boxes	600

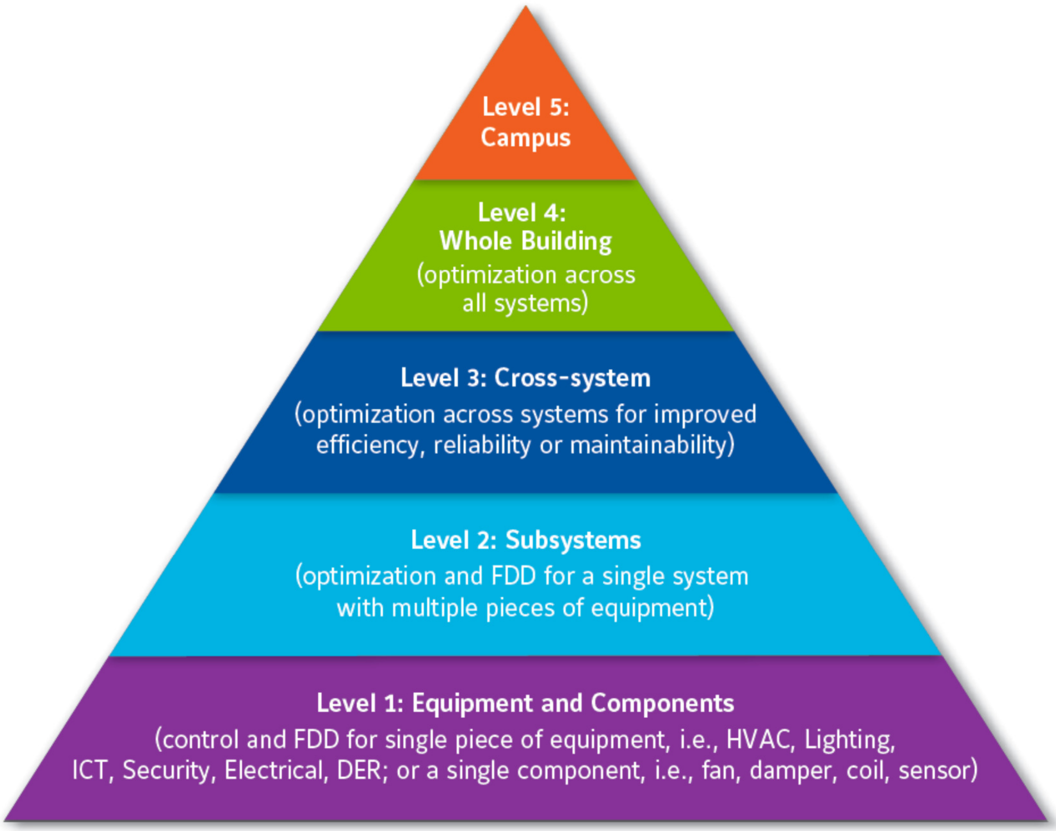
The building lies in mid- east coast climatic region of the U.S.. The cost of operations (both labor and energy) is a function of location. In this document, the costs are for Arlington, VA. The model can be adjusted to evaluate intelligence measures in the same reference building for other locations using a multiplier. For example, costs in New York City are 20 percent higher while costs in Milwaukee are 7 percent lower.

Levels of Influence

The calculation of electrical and thermal energy cost savings is particularly complicated for building intelligence measures. Intelligence can be added to a single piece of equipment, a control loop that controls a set of equipment, a system that supervises many control loops, or an application that controls many systems. For example, adding an application to a building that performs electrical demand response may influence the HVAC, lighting, and IT systems. Defining an intelligence measure's level of influence in the building is key to accurately calculating the energy savings from the measure.

[4] Whitestone Facility Operations Cost Reference 2012 - 2013, North American Edition, Whitestone Research
[5] Ibid.
[6] JCI HVAC Building Model Reference 2004, Johnson Controls Inc.

Figure 1. Levels of Influence



Since each level of influence impacts the intelligence measures of the levels below it at a different efficacy, using a simple interaction model, as we do in this analysis, is limiting. A better regression model is needed to isolate the effect of each measure.

The following sections will list and briefly describe measures that will be included in this analysis, along with the level of influence of each measure. For a detailed description of each measure, with cited references for their energy savings, see Appendix 2.

Chilled Water Plant Intelligence Measures

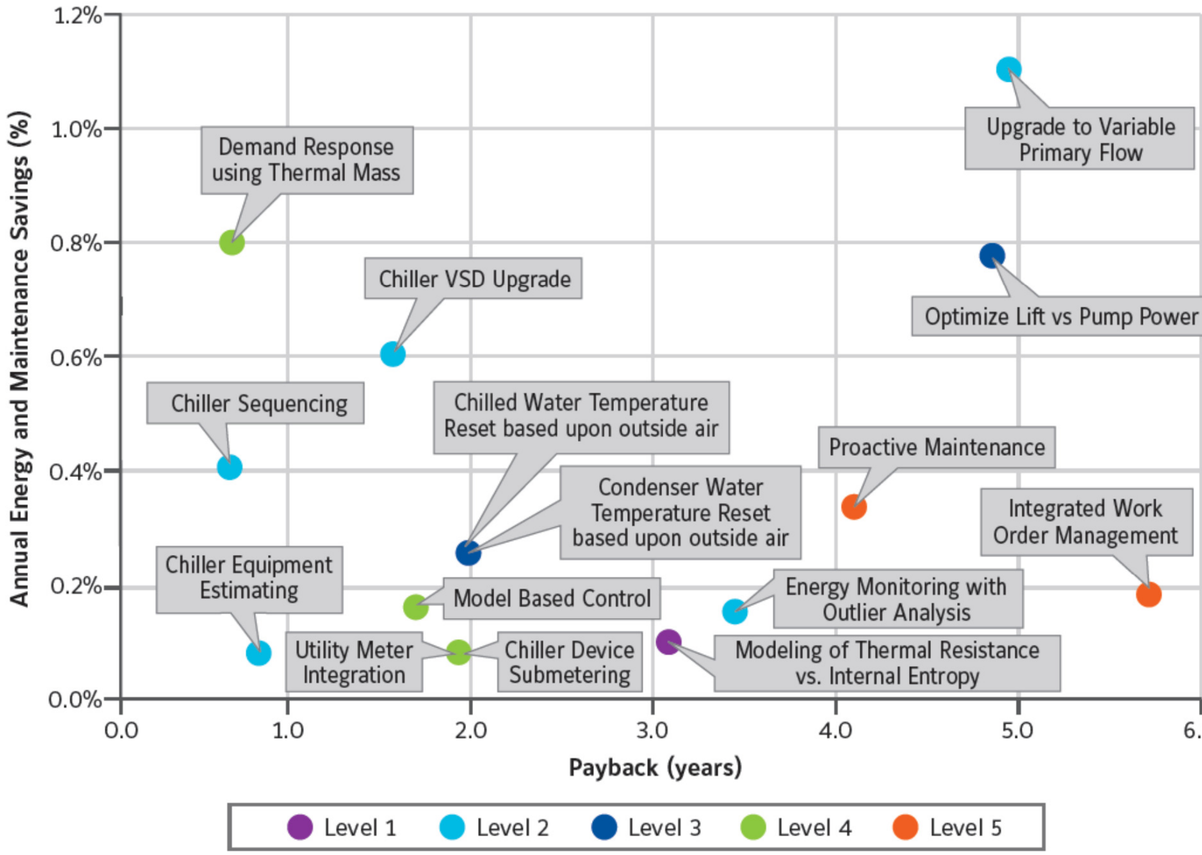
The following is a list of the intelligence measures that can be implemented to improve the intelligence of the chiller plant in a commercial office building.

Improvement	**Level**	**Description**
Modeling of thermal resistance vs. internal entropy	1	Use thermodynamic model of a chiller to indicate chiller faults
Chiller device submetering	2	Meter the electrical power consumption of the chiller so it can be trended.
Chiller equipment estimating	2	Estimate power consumption; trigger an alarm if power exceeds expected bounds.
Chiller sequencing	2	Turn on chillers in a sequence such that each one is in its most efficient operating area

Chiller VSD upgrade	2	Add variable-speed drives to the chiller water pumps.
Energy monitoring with outlier analysis	2	Identify when the chiller plant deviates from statistically expected performance
Upgrade to variable primary flow	2	Modify the chiller to have a variable-flow system.
Chilled water temperature reset based on outside air	3	Adjust the chilled water temperature based on outside air temperature.
Condenser water temperature reset based upon outside air	3	Adjust the condenser water temperatures based on outside air temperatures to minimize power use.
Optimize lift vs. pump power	3	Adjust pump power to minimize chiller and pump energy consumption in a centrifugal chiller.
Demand response using thermal mass	4	Pre-cool the building before demand response events, then curtail load during the event to get utility incentives.
Model-based control	4	Model the chiller plant to predict the time-varying demand of the system.
Utility meter integration	4	Send chiller data to a BAS for monitoring, trending and alarming.
Integrated work order management	5	System automatically prioritizes and issues work orders to repair or replace faulty chiller equipment
Proactive maintenance	5	Preventive maintenance program improves reliability and efficiency.

Figure 2 shows the simple payback plotted against the energy savings for each of the chiller plant intelligence measures listed above. The items that have a quick payback and a high percent energy savings (in the upper left corner of the chart) make the most sense to implement first. These include demand response using thermal mass, chiller VSD upgrade, and chiller sequencing.

Figure 2: Chilled Water Plant Intelligence Measures – Payback vs. Annual Energy Savings



Cooling Tower Intelligence Measures

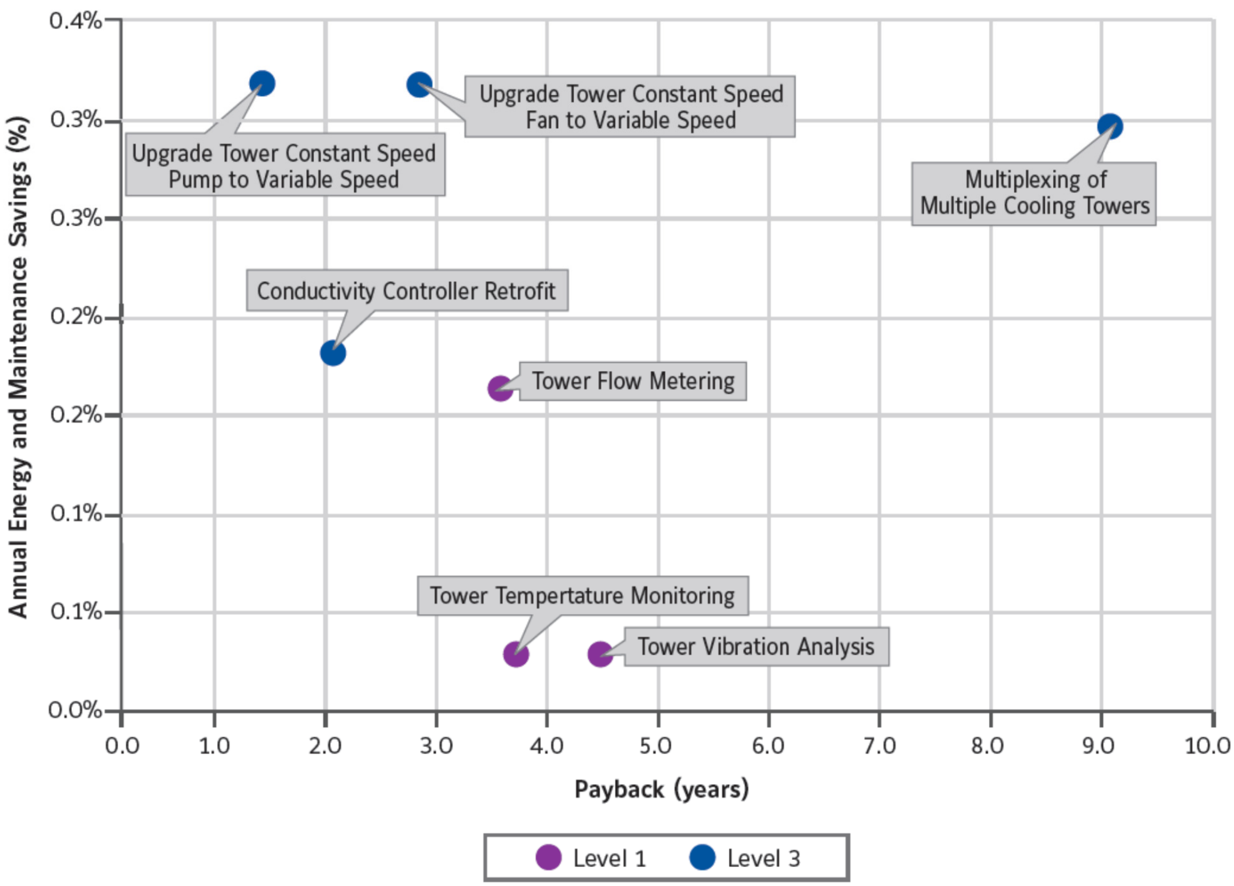
The following is a list of the intelligence measure that can be implemented to improve the intelligence of the cooling tower in a commercial office building.

Improvement	Level	Description
Tower flow metering	1	Instrumenting the cooling tower to monitor the condenser water flow and ensure that it does not exceed statistical norms.
Tower temperature monitoring	1	Instrumenting the dispersion fan and condenser pump to monitor the motor temperature and ensure that it does not exceed statistical norms.
Tower vibration analysis	1	Instrumenting the dispersion fan and condenser pump to trend vibration and ensure that it does not exceed statistical norms
Conductivity controller retrofit	3	Measures the conductivity of the cooling tower water, discharges water only when the conductivity set point is exceeded.
Multiplexing of multiple cooling Towers	3	Run condenser water over as many towers as possible at the lowest possible fan speed and as often as possible to extract the most heat.

Upgrade tower constant speed fan to variable speed	3	Change a constant-speed fan to a variable-speed fan so that it can match the load and temperature difference between the condenser water and outside air temperature.
Upgrade tower constant-speed pump to variable speed	3	Change a constant-speed pump to a variable-speed pump so that it can match the load and temperature difference between the condenser water and outside air temperature.

Figure 3 shows the simple payback plotted against the energy savings for each of the cooling tower intelligence measures listed above. The items that have a quick payback and a high percent energy savings (in the upper left corner of the chart) make the most sense to implement first. These include upgrade tower constant-speed pump to variable-speed, upgrade tower constant-speed fan to variable-speed, conductivity controller retrofit, and tower flow metering.

Figure 3: Cooling Tower Intelligence Measures – Payback vs. Annual Energy Savings



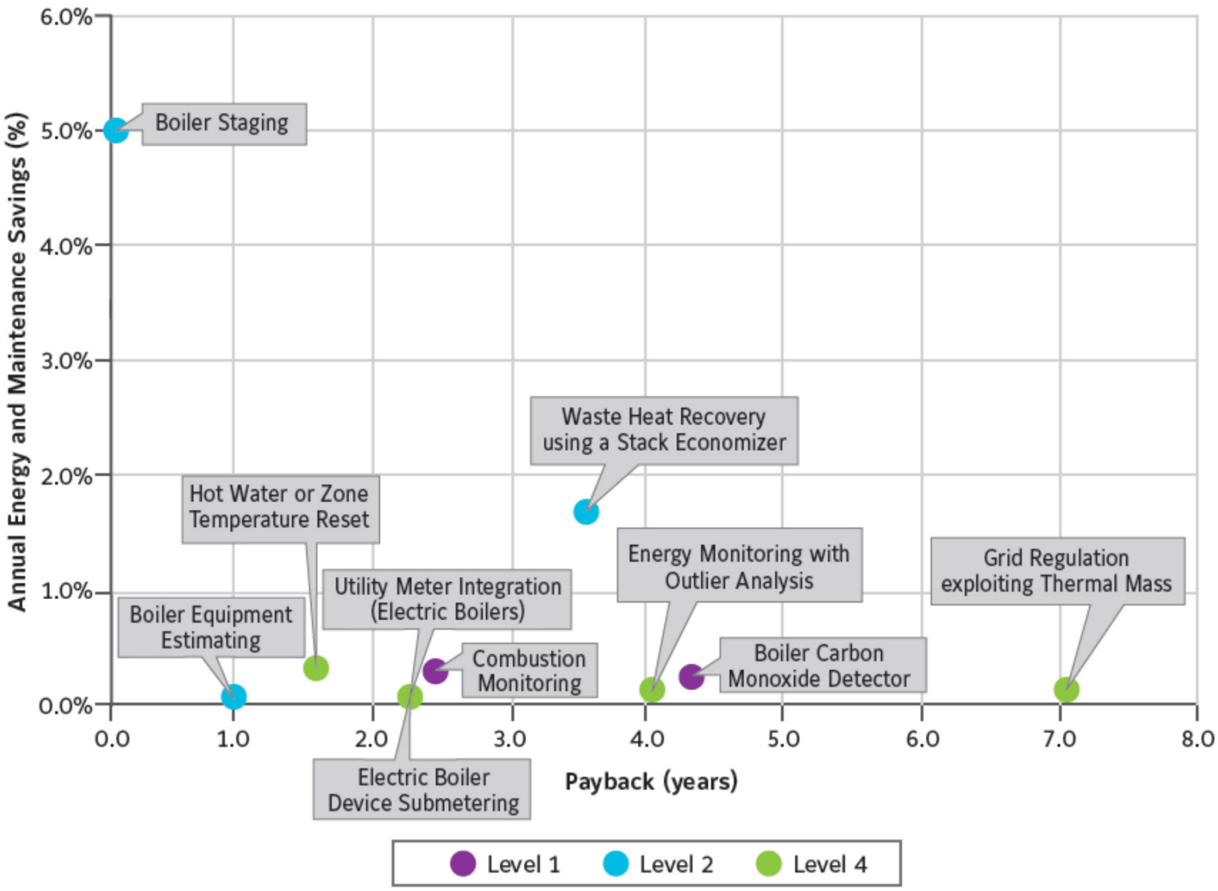
Boiler Plant Intelligence Measures

The following is a list of the intelligence measures that can be implemented to improve the intelligence of the boiler plant in a commercial office building.

Improvement	Level	Description
Boiler carbon monoxide detector	1	Instrument the boiler flue to monitor carbon monoxide, trend the value, and alarm if the CO level exceeds statistical norms.
Combustion monitoring	1	Ensure that the burner fuel-to-oxygen mix is correct to improve the combustion efficiency.
Boiler equipment estimating	2	Trend power consumption of an electric boiler, alarm if power exceeds statistically expected bounds.
Boiler staging	2	Stage multiple boilers to ensure that system load matches boiler output to reduce boiler cycling.
Electric boiler device submetering	2	Meter and trend power consumption of an electric boiler and alarm if it exceeds statistically expected bounds.
Waste heat recovery using a stack economizer	2	Reduce the amount of heat being lost through the flue by installing a waste heat recovery system to preheat boiler feedwater.
Energy monitoring with outlier analysis	4	Use statistical peer analysis to determine boiler performance; alarm outliers.
Hot water or zone temperature reset	4	Reset boiler temperature based on zone temperature.
Utility meter integration (electric boilers)	4	Submeter the boiler and use a BAS for monitoring, trending and alarming.
Grid regulation exploiting thermal mass	4	Receive payments from the utility to modulate boiler temperature based on signals from the grid to help increase grid reliability.

Figure 4 shows the simple payback plotted against the energy savings for each of the boiler plant intelligence measures listed above. The items that have a quick payback and a high percent energy savings (in the upper left corner of the chart) make the most sense to implement first. These include boiler staging and hot water or zone temperature reset.

Figure 4: Boiler Plant Intelligence Measures – Payback vs. Annual Energy Savings



Air Handling Unit/Terminal Unit Intelligence Measures

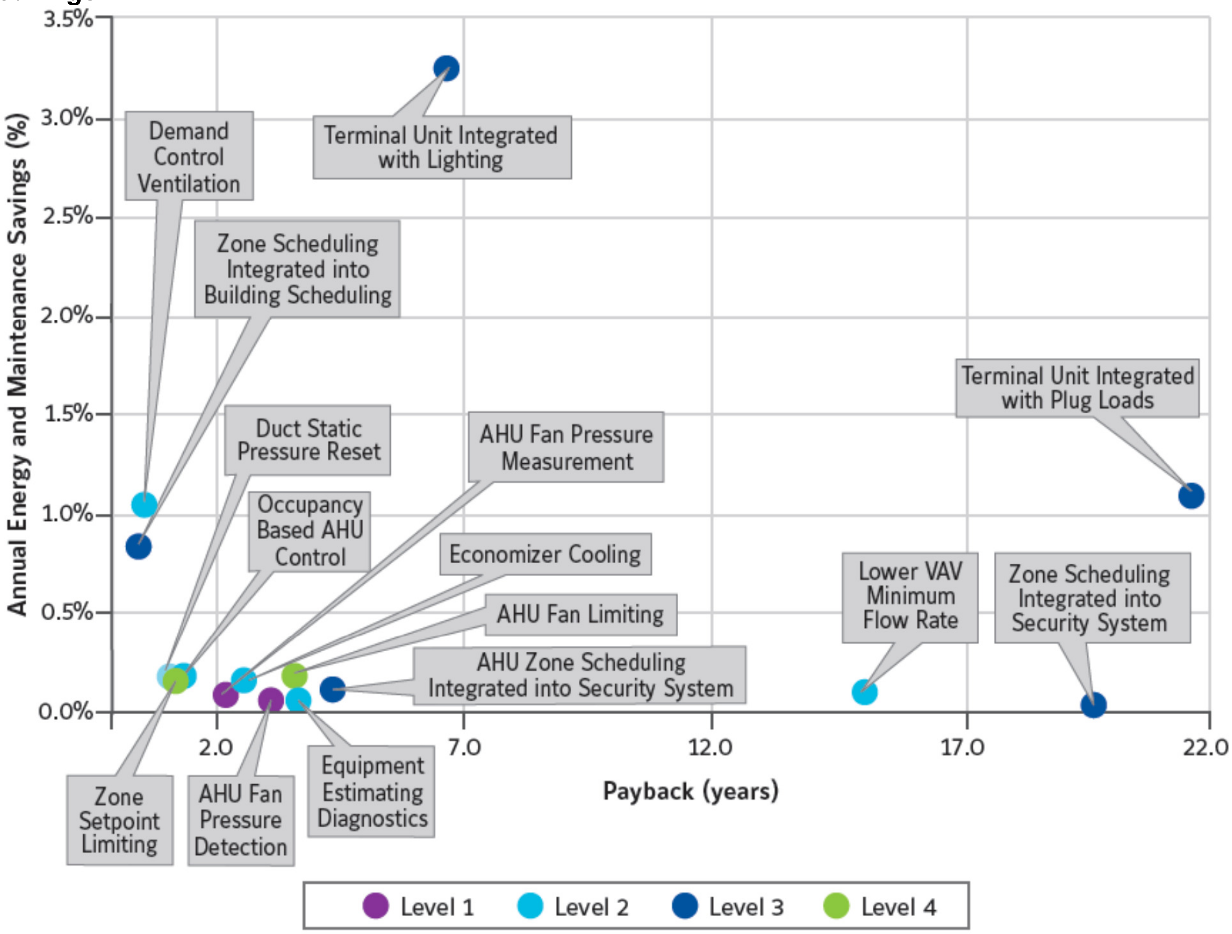
The following is a list of the intelligence measures that can be implemented to improve the intelligence of the air handling units/terminal units in a commercial office building.

Improvement	Level	Description
AHU fan pressure detection	1	Ensures that the fan provides duct static pressure.
AHU fan pressure measurement	1	Trends duct static pressure; alarms if outside normal.
Lower VAV minimum flow rate	2	Lower the minimum airflow rate at each VAV terminal to 30 percent of the maximum flow
Demand control ventilation	2	Regulate ventilation based on monitored CO_2 levels inside.

Device submetering	2	Meter and trend the electrical power consumption of the AHUs and alarm on power exceeding statistically expected bounds.
Duct static pressure reset	2	Pressure is reset and optimized with variable-speed drives.
Economizer cooling	2	Use outside air to provide natural cooling when possible.
Equipment estimating diagnostics	2	Trend the estimated power consumption, provided by the AHU controller, and alarm on power exceeding statistically expected bounds.
Occupancy-based AHU control	2	Reset zone setpoints and reduce airflow when an occupancy sensor indicates that the zone is unoccupied.
AHU zone scheduling integrated into security system	3	Turns off the AHU in zones where the security system indicates there are no occupants.
Terminal unit integrated with lighting	3	Lighting in a zone is controlled by the VAV terminal occupancy status.
Terminal unit integrated with plug loads	3	Plug loads in a zone are controlled by the VAV terminal occupancy status.
Zone scheduling Integrated into building scheduling	3	AHU goes to nighttime set points by matching the building schedule.
Zone scheduling integrated into security system	3	Turns off the AHU in zones where the security system indicates there are no occupants.
AHU fan limiting	4	Increase the zone temperature set points for an entire facility to provide demand response.
Zone Set-point Limiting	4	Increase the zone temperature setpoints for an entire facility to provide demand response.

Figure 5 shows the simple payback plotted against the energy savings for each of the air handling unit/terminal unit intelligence measures listed above. The items that have a quick payback and a high percent energy savings (in the upper left corner of the chart) make the most sense to implement first. These include demand control ventilation, along with a group of other quick-payback items that together would add up to significant energy savings. Two measures from the list above (device sub-metering and terminal unit integrated with plug loads) were excluded from Figure 4, since they had a payback of more than 25 years.

Figure 5: Air handling Unit/Terminal Unit Intelligence Measures – Payback vs. Annual Energy Savings



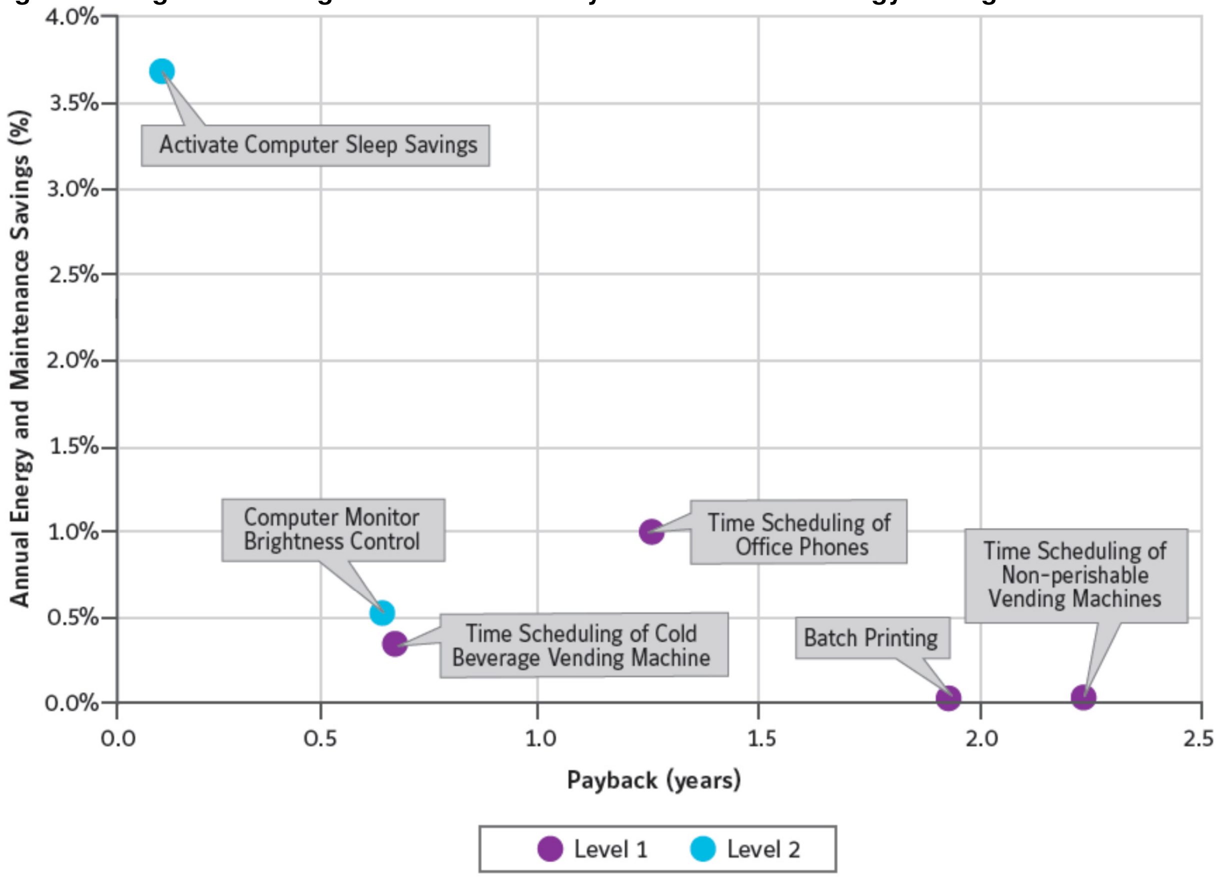
Plug Load Intelligence Measures

The following is a list of the intelligence measures that can be implemented to improve the intelligence of the plug loads in a commercial office building.

Improvement	Level	Description
Batch printing	1	Only time sensitive materials are printed on demand; others are batched together.
Time scheduling of cold beverage vending machine	1	Turn off vending machines when the building becomes unoccupied.
Time scheduling of non-perishable vending machines	1	Turn off vending machines when surrounding area is vacant.
Time scheduling of office phones	1	Turn off newer VOIP phones outside business hours, sending calls to voicemail.
Activate computer sleep savings	2	Reduce active state of computers when not in use.
Computer monitor brightness control	2	Set computer monitors to energy-saving levels.

Figure 6 shows the simple payback plotted against the energy savings for each of the plug load intelligence measures listed above. The items that have a quick payback and a high percent energy savings (in the upper left corner of the chart) make the most sense to implement first. These include activating computer sleep settings, computer monitor brightness control, and time scheduling of cold beverage vending machines.

Figure 6: Plug Load Intelligence Measures – Payback vs. Annual Energy Savings



Lighting Intelligence Measures

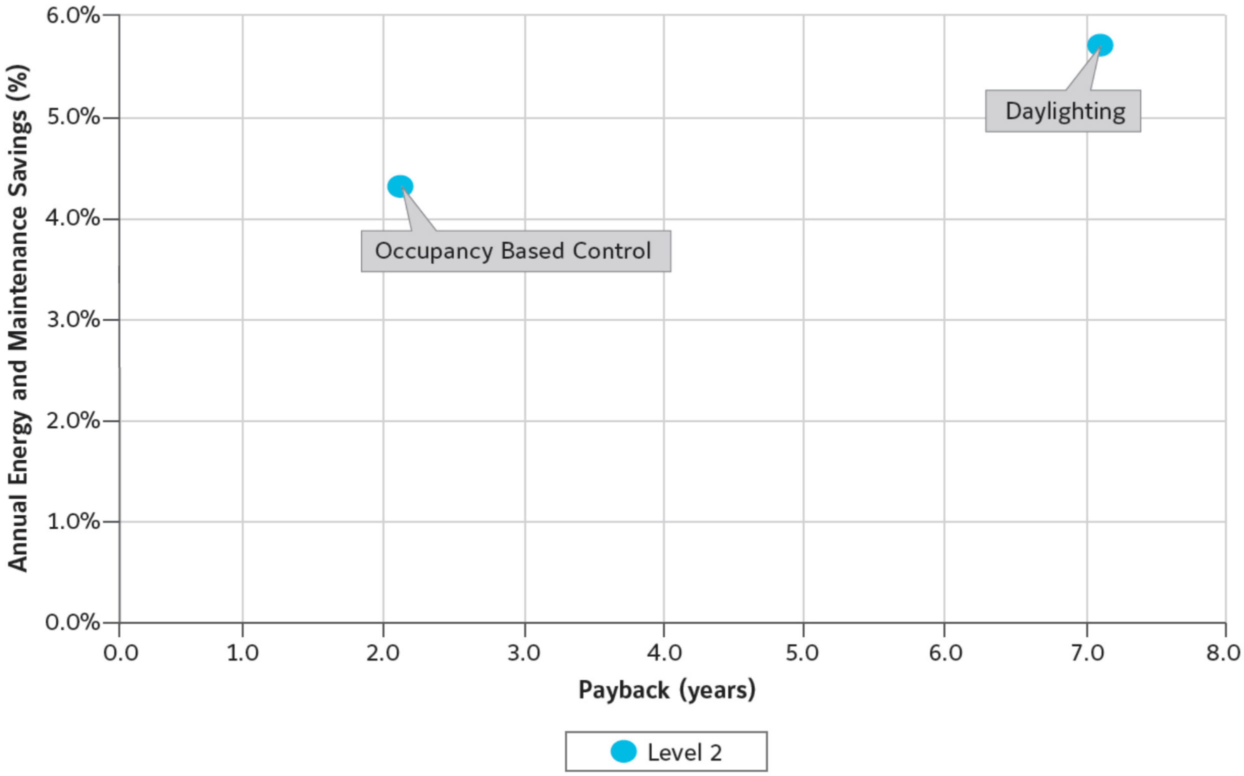
The following is a list of the intelligence measures that can be implemented to improve the intelligence of the lighting in a commercial office building.

Improvement	Level	Description
Electrochromic windows	1	Electrochromic (EC) coatings allow windows to darken and lighten upon the application of a very small electric voltage.
Automatically controlled shading	2	System automatically controls the window shades in response to the amount of daylight
Daylighting	2	Dimmable light fixtures using efficient electronic ballasts, photo sensor controlled.

Occupancy-based control	2	Occupancy sensors turn off lights when a space is unoccupied.

Figure 7 shows the simple payback plotted against the energy savings for each of the lighting intelligence measures listed above. The items that have a quick payback and a high percent energy savings (in the upper left corner of the chart) make the most sense to implement first. These include occupancy-based control and daylighting control. Two measures from the list above (electrochromic windows and automatically controlled shading) were excluded from Figure 7 since they had a payback of more than 25 years.

Figure 7: Lighting Intelligence Measures – Payback vs. Annual Energy Savings



Grouping Measures into Payback Groups

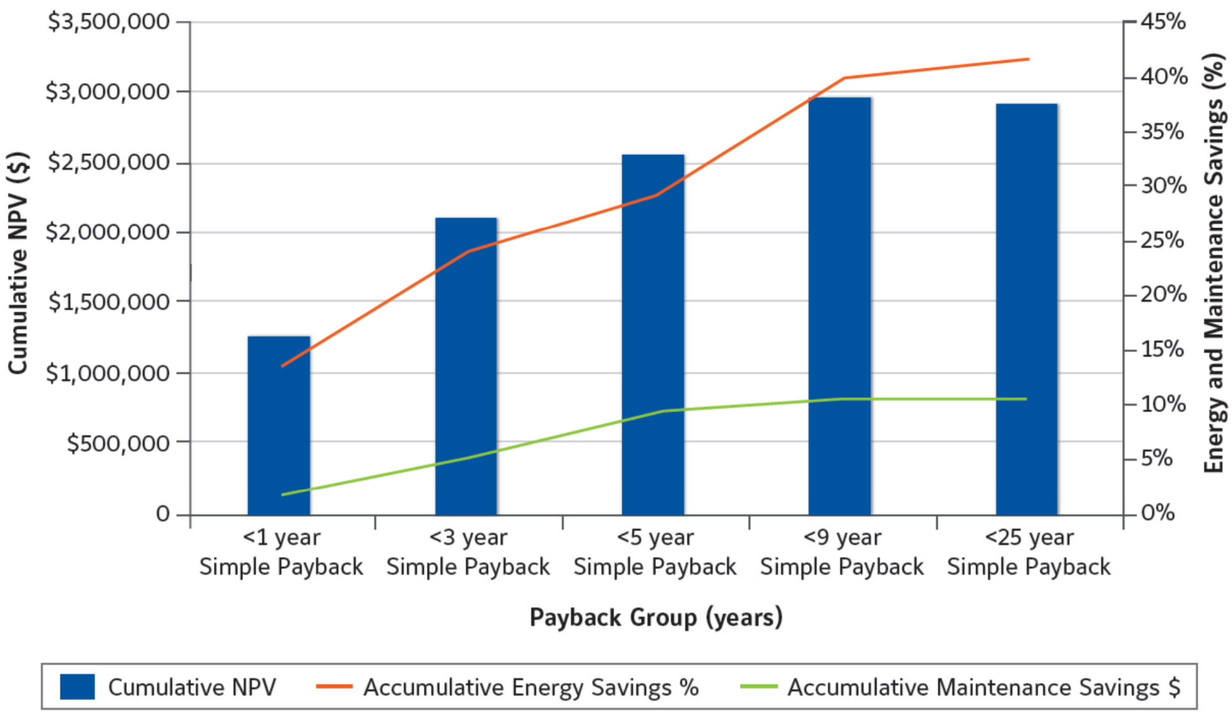
To facilitate decision making, we grouped the measures not by type of measure, but by their simple payback. The measures with less than a 1-year payback are clearly attractive and should be completed immediately. Those with 1- to 3-year or 4- to 5-year payback also meet the payback requirements of many companies and should be completed quickly. Some measures with a 6- to 9-year and 10- to 25-year payback may still be attractive to complete, provided the NPV remains positive.

While simple payback is the most common criterion used to make decisions about investments in energy efficiency projects, it does have some limitations. Some larger projects that generate substantial long-term savings will have a strongly positive NPV, but may have a slightly longer payback time if they require significant up-front investment. NPV can be a better basis for investment decision-making in many cases. As long as the correct discount rate is chosen for an alternative investment (8 percent is used in this paper), a positive NPV means the investment in intelligence will have a higher return than the alternative. In reality, companies sometimes worry about tying up capital in projects that have longer payback, even if the NPV is positive. The following framework looks at groups of measures grouped by their payback, with NPV data layered on top. This methodology will help decision-makers select optimal investments in intelligent building technologies.

All of the measures within each payback group were then added together to show the NPV of the entire group (Figure 8). The biggest gain in cumulative NPV was made by including not only measures with a less than 1-year payback, but also those with a 1- to 3-year payback. Inclusion of measures with 4- to 5-year payback also results in an in total NPV of more than $500,000. The NPV gains are less significant for measures with a 6- to 9-year payback. Cumulative NPV actually drops by $65,000 once measures with a 10- to 25-year payback are added, since many of these measures have a negative NPV.

Figure 8 also adds up the accumulated energy savings and accumulated maintenance savings by group. Once all measures with less than a 5-year payback are included, total energy savings are about 30% percent, with potential to reach more than 40 percent savings if longer-payback items are included. (The energy savings calculations in this example are not adjusted for the ways in which measures will interact with each other, actual energy savings may be lower.) The total maintenance savings are 10 percent once all measures with less than a 5-year payback are completed.[7]

Figure 8: Energy and Maintenance Savings and Cumulative Net Present Value (NPV)



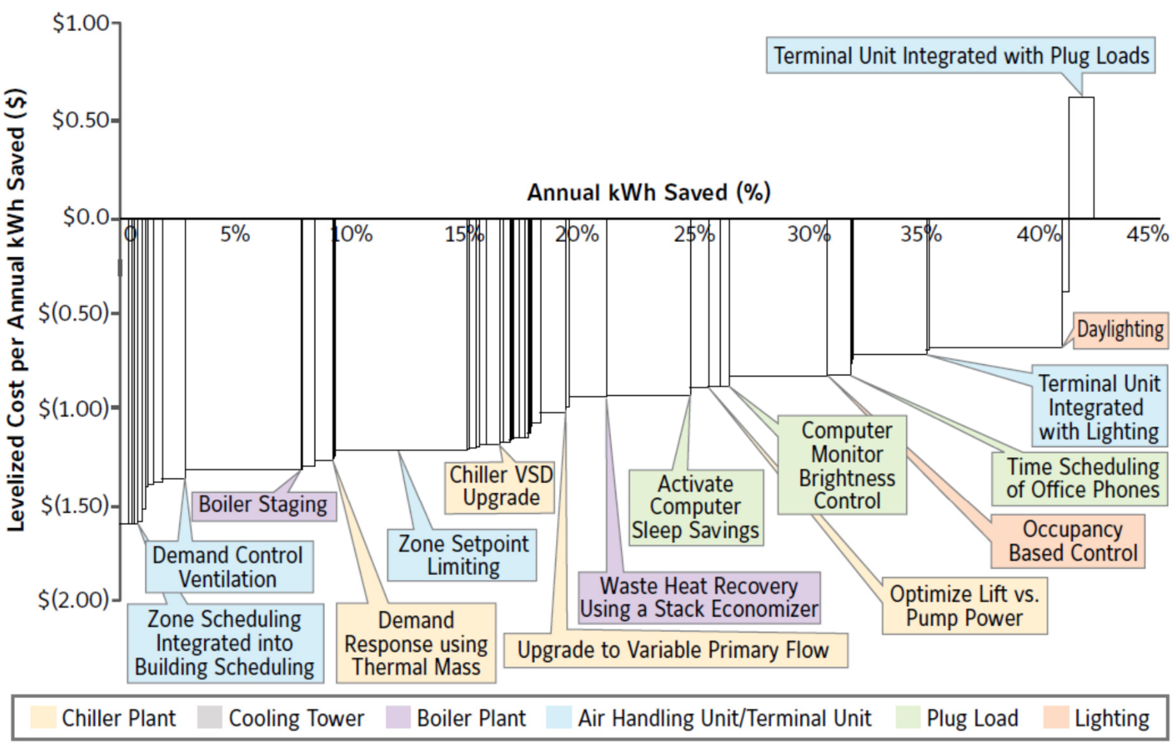
Levelized Cost Curve

Based upon the net present value (NPV) of each measure, we found the levelized cost per annual kWh saved for each measure and organized measures into an annual marginal kWh saved curve (Figure 9). A negative cost on the curve means that there is a positive net present value for that particular measure..

[7] The energy and maintenance savings may actually be somewhat lower than the levels shown here as the model does not account for the fact that a few measures may result in the same energy savings – for example there may be some overlap between the savings due to daylight and occupancy sensors on lights, but those were each calculated individually and their interactions regarding energy savings were not modeled.

The marginal kWh saved curve shows the levelized cost per annual kWh saved of each measure on the y axis. (Only the 55 measures with a payback of less than 25 years were included, as in previous charts.) Levelized cost per annual kWh saved was calculated by taking the negative of the NPV and dividing that by the annual kWh that would be saved through that measure. On the x-axis, the marginal annual kWh saved by each measure is shown. The width of each bar represents the total annual percent kWh saved by each measure. (kWh was used to normalize total energy units of electricity, gas and other fuels. The energy savings calculations in this example are not adjusted for the ways in which measures will interact with each other, actual energy savings may be lower.) Labeled measures are the measures that provide the largest amount of energy savings. They account for 90 percent of the total kWh saved by all measures. The bars without labels account for the remaining 10 percent of energy savings. To keep the scale of the graph readable, three measures with very high levelized cost were excluded: automatically controlled shading, electrochromic windows, and air handling unit device sub-metering.

Figure 9: Levelized Energy Cost Curve with Largest Savings Measures Highlighted



Of the 55 measures that had a payback of less than 25 years, the16 measures labeled in Figure 9 have the greatest amount of energy savings and represent 90% of the energy savings. They come from five of the six categories listed, only the cooling tower category includes no measures that have sufficient energy savings to contribute to the first 90% of energy savings.

Summaries of Savings and Payback by Sub-system Category and Level

In this section we look at the energy savings and the payback by both sub-system category and level for measures with a payback of less than five years. The measures with a payback of less than 5 years still result in energy and maintenance savings of 26.5%

Figure 10 shows the savings and payback by sub-system category. The boiler plant measures have the highest savings among the categories, as well as the second to lowest payback of just 1.2 years. The second most energy savings come from plug load measures with 5.6% savings. These have the lowest payback of only 0.4 years. That said, each category contributes at least 1% to the energy and maintenance savings when measures with less than a five year payback are included. And, the average bundled payback for the whole category is always less than 3 years, even though measure with up to a five year payback are included in the category.

Figure 10: Savings and Payback by Sub-system Category

Category	Total % Energy and Maintenance Savings	Payback for Whole Category (in years, for measures with <5 year payback)
Chiller Plant	4.9%	2.9
Cooling Tower	1.0%	2.4
Boiler Plant	7.7%	1.2
Air Handling Unit/Terminal Unit	2.9%	1.9
Plug Load	5.6%	0.4
Lighting	4.3%	2.0

Figure 11 shows the savings and payback by level. The greatest energy and maintenance savings, for measures with a payback of less than 5 years, come from level 2 with 19.2% savings. Level 2 also has the lowest average payback at 1.4 years on average. Level 2 includes any single system that has multiple pieces of equipment in it – such as occupancy based air handling unit control or dimmable lighting.

Figure 11: Savings and Payback by Level

Level	Total % Energy and Maintenance Savings	Payback for Level (in years, for measures with <5 year payback)
1	2.3%	2.0
2	19.2%	1.4
3	3.0%	2.4
4	1.8%	1.5
5	0.3%	4.1

Conclusion

Improved building efficiency will lower operating costs and improve asset reliability. Simple payback and NPV are common methods for making investment decisions in intelligent efficiency measures. This paper demonstrates the evaluation of intelligence measures for a reference building in Arlington, VA The framework can be applied to any building in any location once it is adjusted for building structural differences and the energy and labor costs of the location.

We analyzed 58 measures from six sub-system categories for our reference building in Arlington, VA. The six sub-systems were the chiller plant, cooling tower, boiler plant, air handling unit/terminal unit, plug load, and lighting. Three of those measures had a payback of over 25 years, and so were excluded from the rest of the analysis. Of the remaining 55 measures, the 16 measure with the largest energy savings result in 90% of the total potential savings. These 16 come from each of the six categories except the cooling tower, which had no measure that resulted individually in a high percent energy savings.

The 47 measures with less than a 5 year payback still result in energy and maintenance savings of 26.5%. The greatest portion of those savings come from measures in level 2, with 19.2% savings from just that level for measure with less than a 5 year payback.

While this paper does not include the way that measures may interact with each other in our calculations of energy savings, it clearly shows that large improvements in the energy efficiency of buildings are possible through the installation of intelligent building technologies. 90% of the efficiency gains and maintenance savings in our reference building come from a group of just 16 measures that are at level 2, i.e. they improve single systems with multiple pieces of equipment in them. These 16 measures are spread across a variety of sub-system categories.

Appendix 1: Assumptions

Costs:

Improvement costs include both hard costs and soft costs. The hard costs consist of new equipment that needs to be added to the system to realize the improvement. Soft costs consist of the labor to configure or program an improvement in the building automation system (BAS). Due to the type of building modeled, it is assumed that a BAS is already installed and operating.

The hard cost of an improvement is assumed to be the retail cost of the equipment installed plus the installation cost of the equipment being installed by trained professionals.

The soft cost of an improvement is assumed to be the labor cost of an Energy Utility Operator,[8] multiplied by an estimate of the amount of time to implement a change.

Savings:

For those measures that will result in maintenance savings, maintenance cost savings are assumed to be proportional to the energy savings of any improvement, since the equipment is operating for fewer hours or at a lower output. The amount of maintenance savings is the maintenance cost of the particular equipment multiplied by the percent energy savings of the improvement.

Electrical and thermal energy cost savings should be calculated based on the cost of energy and the expected efficiency gains from each improvement being considered.

Appendix 2: Intelligence Measures

More detailed descriptions of each intelligence category and measure, along with an outstanding set of references for each, are listed here.

Chiller Plant

There are two primary types of chillers; mechanical compression chillers and absorption chillers. Chillers have multiple components comprising two fluid loops: the cold water loop that feeds the air handling units and the waste heat loop that circulates through the cooling tower.

The main equipment components of a chiller plant include:

- Cooling tower
- Chilled water valves
- Chiller
    - Condenser
    - Compressor
    - Evaporator

[8] Whitestone Facility Operations Cost Reference 2012 - 2013, North American Edition, Whitestone Research

- Condenser water pump
- Chilled water pump

A brief description of the strategies for improving the intelligence of chillers follows:

- Level 1: Equipment and components
    - **Modeling of thermal resistance vs. internal entropy.** Apply a simple thermodynamic model of a chiller over time and determine if the thermal resistance and/or internal entropy have exceeded thresholds to indicate chiller faults[9].

- Level 2: Subsystems
    - Chiller device submetering. Meter and trend the electrical power consumption of the chiller and alarm on power exceeding statistically expected bounds.
    - Chiller equipment estimating diagnostics. Trend the estimated power consumption, provided by the chiller panel and alarm on power exceeding statistically expected bounds.
    - Chiller sequencing. If a plant contains multiple chillers, the system monitors the load and turns on chillers in a sequence such that each one is part-loaded enough to keep it in its most efficient operating area.
    - Chiller VSD upgrade. Upgrade the chilled water pumps with variable-speed drives (VSDs) to match the part-load characteristics of the chiller.
        - Installation = 10 hrs/VSD[10]
        - Unit cost $6,000[11]
        - savings = 6 kW, $4,538[12]
    - Energy monitoring with outlier analysis. Monitor the plant capacity (Q_{evap}) and predict the coefficient of performance (COP) of the chiller. Identify when the plant capacity or COP deviates from statistically expected performance.
    - Upgrade to variable primary flow. Modify the chiller plant from a constant-flow system to a variable primary flow system. Variable primary flow uses a single set of pumps with variable-frequency drives to serve both the primary and secondary chilled water loop.
        - Potential savings: Variable-flow systems reduce the total annual plant energy by 3 to 8 percent and lifecycle costs by 3 to 5 percent[13].
        - Estimated cost: Example upgrade from primary/secondary to variable flow is $27,671[14]; using the Whitestone 2012 cost estimating tool, the cost is $40,500.

- Level 3: Cross-system
    - Chilled water temperature reset based on outside air. Monitor outdoor conditions and reset the chilled-water temperature higher to the point just below where loads can no longer be satisfied.

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[9] Predictive and Diagnostics Methods for Centrifugal Chillers, Jayaprakash Saththasivam, ASHRAE Transactions, Volume 114, Part 1, 2008

[10] Case Study: The ROI of Cooling System Energy Efficiency Upgrades, Whitepaper #39, The Green Grid, 2011

[11] Submetering of Building Energy and Water Usage, Analysis and Recommendations of the Subcommittee on Buildings Technology Research and Development, National Science and Technology Council Committee on Technology, October 2011

[12] Ibid.

[13] ARTI-21CR/611-20070-01, Variable Primary Flow Chilled Water Systems: Potential Benefits and Application Issues, Final Report, Volume 1, March 2004 Air-Conditioning and Refrigeration Technology Institute

[14] Variable Primary Flow Chilled Water Systems: Potential Benefits and Applications, Final Report, Volume 1, ARTI-21CR/611-20070-01, The Pennsylvania State University, 2004

        - Potential savings: An increase of one degree in the chilled water supply temperature can increase the operational efficiency of the chiller by 1 to 2 percent[15].
    - Condenser water temperature reset based on outside air. Higher condenser water temperatures decrease cooling tower fan power but increase chiller power. The optimum operating temperature occurs at the point where these two opposing trends combine to produce the lowest total power use.
    - Optimize lift vs. pump power. In a centrifugal chiller, constantly adjust the pump power to adjust the chiller part load to the point where the combination of the chiller energy consumption and pump energy consumption is minimized.
        - Potential savings: Energy savings of up to 15 percent[16] of pump power.

- Level 4: Whole building
    - Demand response using thermal mass. Reducing the energy consumption of a building during high demand times by precooling the building before the demand event. Cost savings are in the form of a utility incentive.
        - Potential savings: 100 kW electric load reduction[17].
        - Potential energy cost: 4-hour precool of building @ $0.12/kWh
        - Implementation cost: Installation of demand response signaling system.
    - Model-based control. Since the cooling system of a commercial building consumes up to 55 percent of the building's power, a model of the energy consumption over time can be used for planning purposes. The measure includes modeling of the chiller plant to predict the time-varying demand of the system and communicating this to a BAS or energy service provider (ESP) to use in ensuring electrical power during high-usage times.
    - Utility meter integration. Submetering of the chiller to a BAS for monitoring, trending, and alarming.
        - Potential Savings: Case study from the University of California and California State University stated, "The chiller and boiler also operated at night, performing simultaneous heating and cooling; the manual usage readings had not triggered any alarms that would have revealed this problem."[18]
- Level 5: Campus
    - Integrated work order management. System integrates with a continuous diagnostics advisor (system that constantly monitors chiller plant systems to detect problems through abnormal energy consumption and identifies equipment faults) and automatically prioritizes and issues work orders to repair or replace faulty chiller equipment.
    - Proactive maintenance. Preventive maintenance program that improves the reliability and efficiency of a chiller plant by predicting when components will fail and replacing them before failure.

Cooling Tower

Cooling towers are mechanical equipment that provides a method to reject heat from a building's cooling system to the atmosphere. Effective waste heat rejection is key to improving the efficiency of a chiller system. The main equipment of a cooling tower consists of:

- Water valve
- Spray Nozzles

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[15] Best Practice for Energy Efficient Cleanrooms, Tengfang Xu, 2013, Lawrence Berkley National Laboratory
[16] LIT-12011575, Johnson Controls Central Plant Optimization™ 10 Application Note, May 13, 2011
[17] Introduction to Commercial Building Control Strategies and Techniques for Demand Response, Demand Response Research Center, Lawrence Berkley National Lab, May 2007
[18] Submetering of Building Energy and Water Usage, Analysis and Recommendations of the Subcommittee on Buildings Technology Research and Development, National Science and Technology Council Committee on Technology, October 2011

- Suction screen
- Fan
- Condenser pump

A brief description of the strategies for improving the intelligence of a cooling tower follows:

- Level 1: Equipment and components
    - Tower flow metering of the cooling tower loop. Instrumenting the cooling tower system to monitor the condenser water flow, trending of the difference between the input and output flow, and alarming if the difference exceeds statistical norms.
    - Tower temperature measurement of dispersion fan and condenser pump. Instrumenting the dispersion fan and condenser pump to monitor the motor temperatures, trending these temperatures, and alarming if the temperature exceeds statistical norms.
    - Tower vibration analysis of dispersion fan and condenser pump. Instrumenting the dispersion fan to monitor the fan vibration and the condenser pump to monitor the pump vibration, trending of theses vibrations, and alarming if the vibrations exceed statistical norms.

- Level 3: Cross-system
    - Conductivity controller retrofit. A conductivity controller measures the conductivity of the cooling tower water and discharges water only when the conductivity set point is exceeded.
        - Potential savings: Annual water savings with a new cooling tower conductivity controller can be as much as 40 percent. In a large building, this translates into a $1,300 savings in water, chemical, and filter costs[19].

    - Multiplexing of multiple cooling towers. In systems with more than one cooling tower, run condenser water over as many towers as possible, at the lowest possible fan speed, and as often as possible to extract the most heat.
        - Potential savings: The chiller will consume 2.5 to 3.5 percent more energy for each degree increase in the condenser temperature[20].
    - Upgrade constant-speed fan to variable-speed fan. Change a constant-speed fan to a variable-speed fan to reduce energy by varying the fan speed to match the load and the temperature difference between the condenser water and the outside air temperature.
        - Potential savings: Savings of 30 to 50 percent of fan energy have been achieved in many installations by installing VSDs[21].
    - Upgrade constant-speed condenser pump to variable-speed pump. Change a constant-speed pump to a variable-speed pump to reduce energy by varying the pump speed to match the load and temperature difference between the condenser water and the outside air temperature.
        - Potential savings: Savings of 30 to 50 percent of pump energy have been achieved in many installations by installing VSDs[22].

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[19] Evaluating Peak Load Shifting Abilities and Regulation Service Potential of a Grid Connected Residential Water Heater, Harshal Upadhye, Ron Domitrovic, Ammi Amarnath, 2012 ACEEE Summer Study on Energy Efficiency in Buildings

[20] ENERGY STAR® Building Upgrade Manual, United States Environmental Protection Agency, Office of Air and Radiation, 2008 Edition

[21] Variable Speed Pumping, A Guide to Successful Applications: Executive Summary, U.S. DOE Industrial Technologies Program, January 2012

[22] Variable Speed Pumping, A Guide to Successful Applications: Executive Summary, U.S. DOE Industrial Technologies Program, January 2012
Variable Speed Pumping, A Guide to Successful Applications, US Department of Energy, Industrial Technologies Program, May 2004

Boiler Plant

Two types of equipment are used to provide central heat for buildings: boilers and furnaces. Boilers, which produce hot water or steam that is then distributed throughout a building, heat about 32 percent[23] of all U.S. commercial floor space. While furnaces and other heating systems provide the remainder of the heat facilities for commercial buildings, they do not provide a significant energy savings opportunity. The main equipment components of a boiler plant include:

- Burner (or electric heating element)
- Pressure sensor
- Water tubes
- Water pump
- Temperature sensor

A brief description of the strategies to improve boiler intelligence follows:

- Level 1: Equipment and components
    - Boiler carbon monoxide (CO) detection. Instrument the boiler flue to monitor carbon monoxide, trend the value, and alarm if the CO level exceeds statistical norms.
    - Combustion monitoring. Ensure that the burner fuel-to-oxygen mix is correct to improve combustion efficiency.
        - Potential savings: A 3 percent decrease in flue gas O_2 typically produces boiler fuel savings of 2 percent[24].
- Level 2: Subsystems
    - Boiler equipment estimating diagnostics (electric boilers). Trend the estimated power consumption, provided by the boiler panel, and alarm on power exceeding statistically expected bounds.
    - Boiler staging. In systems that have multiple boilers, stage the boilers to ensure that the system load matches the boiler output to reduce boiler cycling.
        - Potential savings: Matching of boiler size and boiler load can save as much as 50 percent of a boiler's fuel use[25].
    - Electric boiler device submetering. Meter and trend the electrical power consumption of the boiler and alarm on power exceeding statistically expected bounds.
    - Waste heat recovery using a stack economizer. Reduce the amount of heat being lost through the flue by installing a waste heat recovery system to preheat boiler feedwater.
        - Potential savings: Stack losses for boilers without recovery are about 18 percent for gas-fired and about 12 percent for oil- and coal-fired boilers[26].

- Level 4: Whole building
    - Energy monitoring with outlier analysis. Use statistical peer analysis to determine boiler performance. Alarm on boilers that are performing significantly worse than others.
    - Hot water or zone temperature reset. Reset the boiler temperature based on the zone temperature. When heating loads decrease, the temperature of the hot water is decreased, reducing energy consumption.
    - Utility meter integration (electric boilers). Submeter the boiler using a BAS for monitoring, trending, and alarming.
        - Potential savings: Case study from the University of California and California State University identified "The chiller and boiler also operated at night,

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[23] ENERGY STAR® Building Upgrade Manual, United States Environmental Protection Agency, Office of Air and Radiation, 2008 Edition

[24] Operations & Maintenance Best Practices, Version 3.0, US Department of Energy, August 2010

[25] Ibid.

[26] Ibid.

performing simultaneous heating and cooling; the manual usage readings had not triggered any alarms that would have revealed this problem.” [27]
    - Potential savings: Every 4°F the boiler water temperature is reduced leads to 1 percent energy savings[28].
- Grid regulation exploiting thermal mass (electric boilers). Modulate the boiler temperature based on a signal from the electric grid. This is used to increase the reliability of the electric grid. A customer is provided an incentive by the utility for participation.

Air Handling/Terminal Units

Air distribution systems bring conditioned air to the occupants of a building. There are two types of air-handling systems: constant volume (CV) and variable air volume (VAV). In a CV system, a constant amount of air flows through the system whenever it is on. A VAV system changes the amount of airflow in response to changes in the heating and cooling load. In this analysis, the building is assumed to contain a VAV system. On average, the fans that move conditioned air through commercial office buildings account for about 7 percent of the total energy consumed by these buildings[29], so reductions in fan consumption can result in significant energy savings. The main equipment components of an air handling unit include:

- Supply and return fans
- Outside air, return air and exhaust air mixing dampers
- Steam and cooling valves
- Heating and cooling coil
- Heat exchanger
- Humidifier
- Humidity, temperature, flow, status and pressure sensors
- Filter

A brief description of the strategies to improve the intelligence of an air handling unit or terminal unit follows:

- Level 1: Equipment and components
    - AHU fan pressure detection. This measure provides supervision of the fan to ensure that the fan is providing duct static pressure.
    - AHU fan pressure measurement. This measure trends the duct static pressure and alarms when the system is outside normal tolerances.
- Level 2: Subsystems
    - Lower VAV minimum flow rate – Lower the minimum air flow rate at each VAV terminal to 30 percent of the maximum flow unless the system violates the ASHRAE minimum airflow standards.
        - Potential savings: For post-1980 buildings, the HVAC savings range from 15 to 25 percent from lowering the minimum airflow set point from 40 percent to 30 percent[30].
    - Demand-controlled ventilation. In a DCV system, sensors monitor the CO_2 levels inside and send a signal to the HVAC controls, which regulate the amount of outside ventilation air that is drawn into the building. Though ASHRAE does not set a maximum allowable CO_2 concentration, the most recent version of the standard recommends that the indoor

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[27] Submetering of Building Energy and Water Usage, Analysis and Recommendations of the Subcommittee on Buildings Technology Research and Development, National Science and Technology Council Committee on Technology, October 2011

[28] Energy Savings Modeling of Standard Commercial Building Retuning Measures: Large Office Buildings, N Fernandez, Pacific Northwest National Laboratory (PNNL), June 2012

[29] ENERGY STAR® Building Upgrade Manual, United States Environmental Protection Agency, Office of Air and Radiation, 2008 Edition

[30] Energy Savings Modeling of Standard Commercial Building Retuning Measures: Large Office Buildings, N Fernandez, Pacific Northwest National Laboratory (PNNL), June 2012

CO_2 level be no more than 700 parts per million (ppm) above the outside level, which is typically about 350 ppm.
  - Potential savings: The potential of CO_2-based DCV for operational energy savings has been estimated in the literature from $0.05 to more than $1 per square foot annually[31].
- Device submetering. Meter and trend the electrical power consumption of the AHUs and alarm on power exceeding statistically expected bounds.
- Duct static pressure reset. Pressure reset can yield additional energy savings in systems that have VSDs installed. By ensuring that the warmest zone is satisfied, the other zones can open fully to keep them satisfied.
- Economizer cooling. Air-side economizers consist of a collection of dampers, sensors, actuators, and logic devices on the supply-air side of the air-handling system. The outside-air damper is controlled so that when the outside air temperature is below a predefined setpoint, the outside-air damper opens, allowing more air to be drawn into the building. On hot days, the economizer damper closes to its lowest setting, which is the minimum amount of fresh air required by the local building code.
  - Potential savings: This measure is most effective in regions that have a cooler shoulder season. The total savings range from a low of 2 percent in Miami to a high of 19 percent in Duluth, Minn.)[32].
- Equipment estimating diagnostics. Trend the estimated power consumption, provided by the AHU controller, and alarm on power exceeding statistically expected bounds.
  - Potential savings: The post-1980 baseline shows higher savings than the pre-1980 baseline because fan energy consumption is a higher fraction of overall HVAC consumption in the post-1980 baseline. Post-1980 savings range from 5 to 7 percent[33].
- Network scheduled control. A zone is set to an energy savings condition during the times outside of the normal work day. This is sometimes called setback or time-clock control.
- Enthalpy-based control. Outdoor temperature and humidity are compared against a predetermined enthalpy setpoint to determine how much outdoor air to accept into the AHU system. In humid climates, up to 50 percent of the cooling system's energy is used to dehumidify conditioned air.
- Occupancy-based Control. Reset zone setpoints to an energy savings condition when an occupancy sensor indicates that the zone is unoccupied. Reduce the outdoor air flow rate to zero when the building is unoccupied.
  - Potential savings: The savings are climate-dependent. In the coldest climates, the heating savings may be as much as 5 to 6 percent.

- Level 3: Cross-system
  - AHU zone scheduling integrated into building scheduling. This measure commands the AHU to revert to nighttime setback mode two hours earlier in the evening on weekdays, letting the building coast toward its unoccupied state while it is still partially occupied.
    - Potential savings: In simulations, this measure keeps the HVAC systems completely off unless the boilers or chillers turn on to maintain the zones at the setback temperatures. In total, this reduces the HVAC system "on" time by 22 hours, out of a total of 92 hours in the baseline. Most locations show HVAC savings close to 24 percent[34].
  - Terminal unit integrated with lighting. The lighting in a zone is controlled by the VAV terminal occupancy status. The occupancy status is set via an occupancy sensor in the zone.

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[31] Demand Control Ventilation using CO_2 Sensors, Federal Technology Alert, US Department of Energy, 2004

[32] Energy Savings Modeling of Standard Commercial Building Retuning Measures: Large Office Buildings, N Fernandez, Pacific Northwest National Laboratory (PNNL), June 2012

[33] Energy Savings Modeling of Standard Commercial Building Retuning Measures: Large Office Buildings, N Fernandez, Pacific Northwest National Laboratory (PNNL), June 2012

[34] ibid

- Terminal unit integrated with plug loads. The outlets in a zone are controlled by the VAV terminal occupancy status. The occupancy status is set via an occupancy sensor in the zone.
- Zone scheduling integrated into building scheduling. This measure commands the VAV damper to close when the building is unoccupied.
- Zone scheduling integrated into security system. Turn off the AHU in zones where the security system indicates there are no occupants. The security system would need to be “location aware” of the occupants.

- Level 4: Whole building
  - AHU fan limiting. Increase the zone temperature setpoints for an entire facility to provide demand response.
    - Potential savings: Global setpoint limiting has potential to save up to 0.5 W/sq-ft in energy[35] during a demand response event.
  - Zone setpoint limiting. Increase the zone temperature setpoints for an entire facility to provide demand response.
    - Potential Savings: Global setpoint limiting has potential to save up to 0.5 W/sq-ft in energy[36] during a demand response event.

Plug Loads

There are two primary types of plug loads: primary loads connected directly to the electrical system of the building, and secondary loads connected to the building electrical system through a power strip. The distinction between these two types of loads is based on the capability to perform power management on the load. A primary load is a stationary device that would be expected to be sophisticated enough to be able to manage its own energy consumption. Examples include printers, refrigerators, televisions and vending machines. A secondary load is typically a low-cost device that would not be expected to be able to manage its own energy consumption. Examples include task lighting, power-supply bricks for laptop computers, phone chargers and space heaters.

Many primary loads in a building are already developed to improve the energy efficiency of a building by meeting U.S. EPA ENERGY STAR® ratings. Launched by the EPA in 1992 and supported in over 40,000 individual products, the ENERGY STAR program was designed to promote cost-effective, innovative solutions for reducing GHG emissions. The program has boosted the adoption of energy-efficient products, practices, and services through valuable partnerships, objective measurement tools, and consumer education. The purchase of products rated by ENERGY STAR should be the first measure adopted to reduce the energy consumption of a smart building’s plug loads. A brief description of the strategies for improving the intelligence of plug loads follows:

- Level 1: Equipment and Components
  - Batch printing. Networked printers rated ENERGY STAR v1.2 and above are designed with multiple operational modes that each consume different amounts of power. The ON mode has two sub-modes: an “active-state” sub-mode used when printing, and a “ready-state” used when the printer is waiting for a print job[37]. In a typical piece of printing equipment, the ready-state power consumption is 64 percent less than the active-state power. In this measure, only time-sensitive material is printed on demand while other

[35] Strategies for Demand Response in Commercial Buildings, David S. Watson, Sila Kiliccote, Naoya Motegi, and Mary Ann Piette, Lawrence Berkeley National Laboratory, 2006 ACEEE Summer Study on Energy Efficiency in Buildings
[36] ibid
[37] Program Requirements for Imaging Equipment – Eligibility Criteria V2.0, EPA ENERGY STAR, Jun-2013

print jobs are batched together and printed at some periodic rate. This increases the amount of time that the equipment is in the ready-state, saving energy.
  - Typical active-state power draw = 185 W[38]
  - Typical ready-state power draw = 66 W[39]
  - Density: 1 piece of imaging equipment per 75 occupants
  - Active-state time reduction: 1 hr/day
- Time scheduling of cold beverage vending machines. A plug load device turns off the vending machine when the building becomes unoccupied. There is a significant energy savings opportunity of 1,300 kWh annually for retrofitting conventional cold beverage machines[40]. A conservative schedule is to have the vending machines on for 12 hours a day during the week and off for weekends and holidays. Stand-alone devices for this function cost $100 to $190[41].
  - Density: 1 beverage machine for each 250 occupants
  - Savings: 1,300 kWh per machine/yr
  - Electric rate: $0.20/kWh
- Time scheduling of non-perishable vending machines. Install a device to turn off power to the vending machines when the surrounding area is vacant. A non-refrigerated vending machine consumes about 360 kWh/year of energy. Stand-alone devices for this function cost $70 to $80[42].
  - Density: 1 snack machine for each 250 occupants
  - Savings: ___ kWh per machine/yr
  - Electric rate: $0.20/kWh
- Time scheduling of office phones. Newer Voice Over IP (VOIP) phones draw on average 2 W[43]. Since they are typically powered from the network, the router can be scheduled to turn off the power to the phones during off-hours. Incoming calls will be directed to voicemail when the phones are powered down to avoid lost calls. A conservative schedule is to have the phones on for 12 hours a day during the week and off on weekends and holidays.
  - Density: 1 phone per occupant, 1 IP router for every 5,000 sq-ft of building
  - Savings: ___ kWh per phone/year
  - Electric rate: $0.20/kWh
  -

- Level 2: Subsystems
  - Activate computer sleep savings. Activate the sleep settings of computers to reduce the active-state time when not being used. ENERGY STAR recommends that computers sleep after 15 to 60 minutes of inactivity; many laptops allow a more aggressive setting of 3 to 5 minutes to extend battery life. In addition, monitors can be dimmed during shorter periods of inactivity to increase energy savings.
    - Density = 1 computer per occupant

[38] Plug Load Best Practices Guide, New Buildings Institute, undated
[39] ibid
[40] Massachusetts Market Assessment and Best Practices for Delivering Plug-Load Energy Efficiency in Businesses-Final Report, PA Knowledge Limited, June 14, 2010
[41] ibid
[42] ibid
[43] Plug-Load Control and Behavioral Change Research in GSA Office Buildings, National Renewable Energy Laboratory, June 2012

        - Implementation: By IT network setting. Uptake of 100 percent using policy setting application with $10/user/year licensing fee[44].
        - Savings = $50/yr[45] or 200 kWh[46] per computer
    - Computer monitor brightness control. Due to the way human eyes perceive light, the brightness of a computer monitor can slowly be reduced to save power and will not be noticed by the user. Energy savings of 17 percent can be attained before the change in brightness becomes noticeable[47]. This measure sets a policy that all LED monitors be configured to reduce screen brightness to the ENERGY STAR energy savings level.
        - Power Consumption: LED Monitor, 18 W
        - Implementation: Policy and support = $2,500
        - Density: 1 monitor per occupant

Lighting

Building lighting systems can be made more intelligent and efficient by ensuring that maximum daylight is used when available, and that lights are dimmed or turned off when they are not needed. Daylight can be maximized through the use of automatically controlled shading or electrochromic glass. Lights can be dimmed and turned off in response to available daylight with photosensors. Dimming of fluorescent lights is enabled by installing electronic ballasts. Occupancy sensors can enable lights to be turned off altogether when a space is unoccupied. A brief description of the strategies for improving the intelligence of lighting follows:

- Level 1: Equipment and components
    - Electrochromic (EC) windows. EC windows have coatings that allow them to darken and lighten upon the application of a very small electric voltage. With the proper sensors and control algorithms, an EC window system in a large commercial building can automatically darken the windows when the sun is high and its rays are heating the interior, thus reducing the solar heat gain and the need for air conditioning. As the sun sets or clouds cover the sky, the system would move the windows back toward transparency, maximizing daylighting and reducing the use of electric lighting. Early studies at Berkeley Lab suggested they could reduce a commercial building's annual lighting energy use from a few percent to roughly 25 percent or more. Cooling energy savings aren't included here but would be significant. We will assume 15 percent savings for this paper. Only the fluorescent portion lighting (71 percent) is included in the calculation, since it is dimmable.
        - Window area: 40 percent, since the reference building was built before 1980. The percent windows assumption is dependent on building structure and design elements.
        - Cost per square foot of window: $45 to $70[48], median $57
        - Installation cost: $143 per square foot[49]
- Level 2: Subsystems

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[44] Massachusetts Market Assessment and Best Practices for Delivering Plug-Load Energy Efficiency in Businesses-Final Report, PA Knowledge Limited, June 14, 2010

[45] Plug Load Best Practices Guide, New Buildings Institute, undated

[47] Plug Load Best Practices Guide, New Buildings Institute, undated

[48] Navigant Research, *Smart Glass: Electrochromic, Suspended Particle, and Thermochromic Technologies for Architectural and Transportation Applications: Global Market Analysis and Forecasts. 2013*

[49] http://venturebeat.com/2013/08/19/heliotrope-smart-glass/

- Automatically controlled shading. A system that automatically controls the window shades in response to the amount of daylight can result in significant energy savings. Savings for automatic systems vary widely depending on the size and type of windows and the size of the office. Having automatic shades instead of manually adjustable shades (which occupants may often leave down during the day) can result in 20 percent additional energy savings on lighting by enabling additional dimming.[50] Only the fluorescent portion lighting (71percent) is included in the calculation, since it is dimmable.
  - Windows area: 40 percent since the reference building was built before 1980. The percent windows assumption is dependent on building structure and design elements.
  - Installation: $48/sq-ft[51]
- Daylighting. Dimmable lighting fixtures enable daylighting, saving energy in two ways, first by using efficient electronic ballasts, second by dimming the lights below full output when daylight is available. which are
  1. Electronic ballast conversion. Controllable electronic ballasts replace magnetic ballasts for fluorescent lights. They increase lamp-ballast efficacy, leading to increased energy efficiency and lower operating costs. Electronic ballasts operate lamps using electronic switching power supply circuits. Electronic ballasts take incoming 60 Hz power (120 or 277 volts) and convert it to high-frequency AC (usually 20 to 40 kHz). By converting input power to the proper lamp power, they operate fluorescent lamps at higher frequencies, reducing end losses. Lamps operating at these higher frequencies produce about the same amount of light, while consuming 10 to 25 percent less power[52]. A median of 15 percent will be assumed for this study.
     - Density: 1 ballast per fluorescent light, minimum lighting density = 1.2 W/ft^2. Assuming 120 W fixtures, the reference building would need 250 fixtures. In a typical office building, lighting is close to the number of VAV terminals (600). Assume 600 for the reference building.
     - Cost = Ballast Cost + Installation Cost. Assume $20/ballast and $250/ballast installation for $270 total.
  2. Electronic ballasts also enable fault detection and dimming for florescent lighting. Dimming can reduce lighting levels to their lowest acceptable level and reduce lighting at times when daylight is abundant. Photosensor-controlled lights with continuous dimming from 40 to 100 percent of full output, use about half as much electricity as standard non-dimmable fixtures. The overall savings will be somewhat less due to occasional overcast conditions, shorter days during the winter, and the fact that daylighting is not possible for the interior space, resulting in an actual lighting energy savings of 32 percent.[53] Only the fluorescent portion lighting (71 percent) is included in the calculation since it is dimmable.

[50] Reinhart, C.F. (2002) Effect of interior design on the daylight availability in open plan offices. National Research Council of Canada, Internal Report NRCC-45374, NRC: Ottawa.
[51] Huang, J. et al. (2006) "Preliminary evaluation of the energy saving potentials of exterior operable window shading systems for residential buildings in California climates" LBNL.
[52] http://www-is.informatik.uni-oldenburg.de/~dibo/teaching/mm/pages/light-fundamentals.html#ballests
NLPIP. (2000) "Electronic Ballasts: Non-dimming electronic ballasts for 4-foot and 8-foot fluorescent lamps". Volume 8, Number 1. RPI.
[53] Energy Center of Wisconsin. (2005) "Energy Savings from Daylighting A Controlled Experiment." ECW Report Number 233-1

i. Density: In a typical office building, lighting is close to the number of VAV terminals (600). Assume 600 for the reference building.
ii. Cost = Photo sensor + Installation Cost. Assume $1/photo sensor and $250/ballast installation to enable dimming for $251 total.

- Occupancy-based control. Occupancy-based control is one of the most effective energy savings opportunities. It covers times when a space is unoccupied during a normally occupied period and when a facility is unoccupied outside the normal work day, including evenings, weekends and holidays. The energy savings from occupancy sensors vary significantly depending on the level of occupancy and how well occupants already do at turning off lights in unoccupied spaces. The EPA says installing occupancy-based lighting controls will save 13 to 50 percent in a private office; the Electric Power Research Institute says the average is 25 percent% savings[54]. Higher savings are often seen in conference rooms and corridors that are occupied less of the time.

iii. Density: 1 sensor per 1,000 sq-ft
iv. Sensor cost $20. Installation cost $250/sensor.
v. Savings: 25 percent lighting energy savings

[54] http://infohouse.p2ric.org/ref/32/31316.pdf

Small and Medium Enterprises and "Minor" Players Have Large Energy Management Problems

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Abstract

Very little is known about physical and energy characteristics of the UK non-domestic stock, let alone the distribution of its energy management opportunities. This paper presents new empirical data on the existing landscape of meters and leases in the UK, with a particular focus on SMEs and other "minor" players. To characterize the energy landscape in the underserved and poorly understood SME market, we surveyed participants in an online building energy management and data analytics service called "sMeasure." This service provides assistance to roughly 100 different organizations working in about 1000 buildings, and it includes clients as diverse as the Church of England, Royal Albert Hall, and the YMCA. Survey questions gathered data on metering infrastructure, as well as addressing basic building ownership and lease characteristics. These data contribute to a developing database on the technical and legal infrastructure in small and medium enterprises and other "minor" subsectors. The results show that SMEs and other minor players are generally "data poor" and have legacy meters that are read only annually or quarterly. A few of the respondents rent properties through leases that do not permit permanent alterations to the premises, including the meter. Based on this exploration, the conclusions offer some insights into how these organizations--when interested--may be able to augment their legal, organizational, and technical infrastructure to enable better energy management.

Introduction

The non-domestic building and organizational infrastructure in the UK is highly varied. Most larger organizations operate in a mix of older and newer properties with different physical and technical energy characteristics. Some organizations have energy managers; others do not. Some organizations have smart meters and data to analyse; some even have analysts to work with the data, but many do not. Some organizations are owner-occupiers; others are landlords or tenants. A lack of information about the distribution, combination, and effects of these variables turns energy management in the non-domestic sector into a stubborn and "wicked" problem [1] rather than one that is "tame" and easy to solve.

From a policy perspective, little is known about physical and energy characteristics of the UK non-domestic stock, let alone the distribution of its energy management opportunities. Government models for the sector are based on data from the 1990s which are in urgent need of updating [2]. The Department of Energy and Climate Change has launched a project to develop a new data set, but these efforts are concentrating on larger sectors and are therefore unlikely to capture the full diversity of issues for small and medium enterprises (SMEs). The energy management problem is particularly acute for many SMEs, typically without an energy manager, who have been shown to not be able to understand their existing energy bills, let alone improve their energy usage profiles using comparative feedback [3]. Further, there may be problems with access to data, control, and authority in buildings that are leased rather than owner-occupied.

This paper explores the issues of energy management in SMEs and other understudied building types. It begins with a background section on some problems involved in under-explored areas: what is (un)known about SMEs and other minor subsectors, leases, energy management practices, and metering infrastructure. This background builds a concept of the groups that have lower ability to measure and manage their energy use, which we call the “minor leagues”. These groups are often either data poor, analytically underprivileged, or both. Next, it describes the work of a small company called “Pilio” that works with several different types of “minor league” players, assisting them to enrich their data streams and analytical capabilities. It then presents new empirical data on the existing landscape of meters and leases in the UK, with a particular focus on arts facilities and churches. Through survey results coupled with Pilio’s contextual knowledge of the data set, it provides a snapshot of the energy interests and challenges faced by organizations that are *not* the main target of government policies, regulations, or assistance. In conclusion, it offers some insights into how these organizations--when interested--may be able to augment their legal, organizational, and technical infrastructure to enable better energy management.

Background: Into the Unknown

Much of the energy research on non-domestic buildings focuses on largest end-use sub-sectors. The UK Valuation Office Agency (VOA) defines four high level bulk classes of premises: shops, offices, factories, and warehouses; at the lowest level of detail, however, the VOA identifies as many as 400 categories [4]. Most of the energy end-use attention focuses on the first two high level categories (office and retail), and there are specialists who focus on hotels, schools, hospitals, and other major building types. “Major” in this instance is often defined in terms of percentage of floor area; social or economic importance; or energy intensity.

However, we also know that these major subsectors alone do not capture the complete picture of the non-domestic market. As carbon reduction targets ratchet up, is it possible to achieve 80% reductions just by looking at the major sectors? Is it fair to leave smaller, more diverse, or less energy-intensive users to fend for themselves? What are the opportunities to make change in and across smaller or more diverse building types?

This background section provides a brief context for discussion on SMEs and other niche sectors, as well as the legal, organizational, and technical infrastructure that can enable or disable energy management practices.

The Minor Leagues: SMEs and Others

If office and retail are the dominant sectors, what are the non-dominant or "minor" sectors? In 2010, the UK Department of Climate Change commissioned a study of what it called the “unconstrained” sector, which includes both private (usually SME) and small public sector organizations falling “outside of existing policy tools” [5, p. 4]. The report estimates that this sector is responsible for 20-40 Mt CO_2 and shows there is great diversity within the “sector”:

> The research has shown that there are different groups of sites and different ways of examining the unconstrained population and their differing support needs. Some are positive and keen to take action, others see only barriers. Some are approaching energy efficiency action from a position of knowledge and recognising their limitations, some erroneously believe they are doing everything possible. Some sites have a large amount of control over and interest in their site (i.e. they own it and pay the utility bills), others do not. [5, p. 51]

Although this report recognizes that whether the premises are owned or rented (part of what we call “legal infrastructure” below) affects what respondents can do, the report does not address the organizational or technical infrastructure of the respondents in any coherent way. Accordingly, the results provide little insight into what organizational or physical changes might be made to help these groups make the most out of their situations. This paper represents explores these issues in greater detail, with particular attention to underserved (and unconstrained) populations.

What is an SME?

To begin with, it is useful to define what is and is not an “SME.” The European Commission defines small, medium, and micro businesses based on the number of employees and how much money they make (see **Error! Hyperlink reference not valid.**).

Table 1. European Commission SME definition

Company category	Employees	Turnover	or	Balance sheet total
Medium-sized	< 250	≤ € 50 m		≤ € 43 m
Small	< 50	≤ € 10 m		≤ € 10 m
Micro	< 10	≤ € 2 m		≤ € 2 m

Source: [6]

In contrast, the US government-led Environmental Protection Agency’s Energy Star program focuses on “common types” of small businesses, rather than size or turnover. Common business types for which the EPA provides energy efficiency information are: auto dealers, grocery and convenience stores, home-based businesses, lodging, renters and tenants, and restaurants [7].

In the US, 50% of all economic activity is attributed to small businesses, and this sector is also responsible for employing 50% of the workforce. It has been argued that sole proprieters are particularly important as a part of the business sector because they are able to innovate due to a short decision chain [8]. However, it has also been argued that because small organizations have fewer staff members who have to multi-task rather than specialize, this makes it hard for small businesses to innovate [5].

For this paper, we are interested in looking at any kind of understudied organization, whether it is “business” or other kind of organization, such as a non-profit.

What do we mean by “other”?

In terms of “other” organizations, these are even harder to define than SMEs. Non-profits, for instance, can be very large (e.g., universities) or quite small (e.g., a single volunteer with no dedicated staff). What makes them interesting from an energy point of view is the fact that the core “business” of these other organizations is not to make money. Instead, it may be to provide a better community, a healthier populace, a more educated citizenry, or some other goal. Looking at non-profits also helps to introduce non-economic motivations for energy actions (including but not limited to what the DECC study [5] calls “altruism”). For example, the level of concern, organizational capacity, and technical condition of an organization’s portfolio have been found to be important factors in understanding the energy actions that organizations of all shapes and sizes do (and do not) take [9, 10].

Although the minor leagues are not a major focus of energy efficiency efforts from a policy perspective, there is some indication that these groups are interested in improving their energy performance. The utility supplier Npower surveyed its SME members and found that 42% had reduced their energy use by 5-10% [11] . A larger number (59%) said they planned to increase their energy efficiency initiatives. However, these businesses wanted further support for their efforts; 43% said the government did not offer useful advice in this area. We argue that part of the reason why government advice may not seem to be useful in the UK is that the advice is keyed only to the size of the organization, not its core business (or central concern, in the case of non-profits). Moreover, little information is available about or directed towards the infrastructural challenges these players face due to legal, organizational, and technical aspects of their operations.

Energy Infrastructure in Organizations: Legal, Organizational, and Technical

There are many different factors that can influence the uptake of energy efficiency measures and strategies in businesses and other organizations. In this paper, we look at three broad categories of factors that that shape how organizations can pursue their goals: legal, organizational, and technical. We call attention to these factors as different kinds of "infrastructure" that are largely taken for granted in the daily operations of most organizations. Although these parameters can be changed over time, they generally set the frame in which most short term or "normal" activity and decision-making occurs.

What is legal infrastructure?

By legal "infrastructure" we refer to the legal parameters that shape how buildings are owned and used. These parameters affect what kinds of changes owners can and cannot make to their premises (e.g., for health and safety reasons, or because of cultural and historical significance) and include energy and building regulations. Of particular interest in this area from an energy management point of view is the "split incentive" problem between tenants and landlords. Half of the total UK stock of 'core' commercial buildings (shops, offices and industrial premises) is occupied by tenants [12]. There is little information available on the percentage of tenants in what we have defined above as the "minor leagues." Energy management opportunities in leased properties depend on the physical premises, the varying organizational capacities of both landlord and tenant, and the language of the lease itself. Most leases do not permit tenants to make alterations to the premises or require landlords to share energy data with tenants; even "green" leases have been found to vary in the extent to which they allow alterations and data sharing [13].

What do we know about organizational infrastructure with respect to energy?

Currently, all firms and organizations pay energy bills, but not all actively "manage" energy. Where energy management does occur, it is usually driven by financial concerns or corporate social responsibility, rather than being treated as a strategic business opportunity [14]. The presence or absence of an energy manager is one important indicator of organizational capacity to manage energy; an energy reduction plan is another. A recent Major Energy Users Council (MEUC) survey in the UK [15] found that 75% of respondents said they have at least one staff member responsible for energy, but the rest have not allocated staff time to manage energy concerns. 62% of respondents had a clearly defined energy reduction strategy for their business, but the remainder did not. These results indicate gaps in organizational capacity to manage energy, even amongst self-defined major energy users. Staffing is an acute problem for many SMEs and other minor players, typically without an energy manager, who may not have the necessary information to improve energy usage profiles.

Technical infrastructure: How do meters matter?

Although energy metering is the key to building energy management programs, it is often (1) not done and (2) not done well. A Carbon Trust study found there are approximately 2.7 million manually-read meters in UK SMEs, which are read only quarterly or annually [16]. Many businesses do no monitoring at all, paying bills being their only exposure to energy use and cost. Some businesses manage to take manual meter readings and some have real time meters installed at the fiscal meter level – but normally only for electricity. Real time meters are expensive – 1/2 hour electricity meters are only mandated for the largest businesses. Data that are automatically collected from the meter are often not easy to get back from the supplier; online software can be cumbersome and not attuned to the user. The smart meter roll out programme in the UK attempts to overcome some of these problems. There are plans to replace and upgrade 53 million electricity and gas meters by 2020 [16]. There are still, however, questions about how the smart meters will roll-out, and to whom; also whether users have easy access to their data.

A data gap has opened between the groups that have better meters and energy management infrastructure and those that do not. This gap will persist at least until the smart meter rollout has been completed, and possibly beyond. Smart meters tend to be targeted at the main fiscal electricity meter for the premises, and are often thought to help the utility (e.g., with billing and possible real-time pricing in the future) more than the user. A metering regime targeted towards users (instead of utilities) might take a more detailed and diverse approach: measuring energy use at the meter, sub-meter and appliance level, for gas, electricity, water and oil.

A Segmented Socio-Technical Approach

Based on the background discussion above, the paper introduces a segmented socio-technical approach to work with and learn from different configurations of building energy data and ownership in the existing UK non-domestic stock (see **Error! Hyperlink reference not valid.**). This approach uses the concepts of "data rich" and "data poor" to identify and map energy-related infrastructure, as well as barriers to and opportunities for change. We define "data rich" as a Platonic ideal archetype: an organization that is able to gather, analyze, and use energy data to manage its premises in perfect harmony with its core strategy and central concerns. The reality is somewhat messier and inexact. Real organizations fitting this category will have lots of data—generally achieved through automatic meter reading (AMR)—and an energy manager of some description. In contrast, a "data poor" organization is one without access to real-time data and lacking the in-house analytical capacity to measure, map, and understand energy issues.

This typology is a heuristic model designed to help define and categorize research assumptions about the nature and distribution of firms and organizations with respect to energy issues. The horizontal categories recognize that there are three kinds of ownership types in the market: owner-occupiers, landlords, and tenants, each of which is subject to a different kind of legal infrastructure. The categories on the right split these three ownership types into data rich and data poor categories, resulting in a typology of six different firm types.

Table 2. Socio-technical segmentation of the UK non-domestic stock

Segmentation of the UK Non-Domestic Market		**Data Rich** (e.g., an organization with AMR and an energy manager)	**Data Poor** (e.g., an organization with legacy meters and no energy analysis)
Owner Occupied		A	B
Leased Space	**Landlord**	C	D
	Tenant	E	F

This segmentation model was designed for a broader investigation of the firms operating in the retail market in the UK [17]. It provides an initial framework that allows for a more nuanced characterization of firms and organizations beyond "large" and "small." It also enables more clarity about preconceptions of where certain players in the field would be located.

For the current research, we did not aim to "fill in" the table. Instead, we intended to concentrate on groups we believed would be "data poor." For the current research, the authors guessed that most SME or "minor league" players would be in the "data poor" category (Types B, D, F). We further anticipated that many SMEs and minor league players would be tenants (Type F) rather than owners or landlords. As discussed below, our sample reflected some but not all of these initial assumptions.

Methods

To empirically explore energy management issues from the perspective of the "data poor", we worked with a company called Pilio and performed an online survey of their members. This was a convenience sample rather than a statistically representative one. We therefore offer the insights below as exploratory rather than explanatory research.

Working with the (Data) Poor: Pilio and sMeasure

Academics and researchers who are interested in understanding energy use in buildings have a hard time getting access to detailed consumption data that could be used to increase their own knowledge as well as those of policy makers and energy users. In the UK, a company called Pilio[1] aims to bridge this particular information gap.

Pilio

Pilio is a company oriented towards homeowners and other customers that lack electricity and gas meters that can be read remotely and automatically. Small customers often have to read their own meters anyway to avoid estimated bills. So technically, they already have their own data. But many of them don't know how to *use* this data. Pilio provides energy management advice and weather-adjusted analysis to help turn data into useful information. It also asks its customers to contribute their information to Pilio's data set. By contributing their data to Pilio, they agree to be a part of an evolving dataset that can identify clusters of buildings by owner as well as by type or size. This will help researchers to understand how different types of owners manage their properties, while helping owners understand their buildings better, and in a broader technical and environmental context. Pilio is working with some unusual clients, including the Church of England and a network of theatres and performing arts venues.

sMeasure

sMeasure is an online energy management tool developed by Pilio as a complement to its initial offering, iMeasure. iMeasure was designed for homeowners, sMeasure was designed for small businesses. sMeasure was first made available in an alpha version in 2007, and it has collected a number of followers since then. Within sMeasure, there are currently 1855 registered buildings; 1498 registered businesses; and 1102 registered users. These numbers show it is not a one-to-one mapping between users, buildings, and businesses. Some businesses have multiple buildings; some users may have multiple businesses. Like many other websites, sMeasure has its share of users who joined but do not actively use the service. The executive director of Pilio estimates that about a third of the users actively use the software (~350).

Survey of sMeasure users

To learn whether some innovative metering techniques might be of interest to their members, Pilio planned to survey their members regarding their metering infrastructure. The authors worked with Pilio to extend the survey and address basic building ownership, lease, and energy management characteristics. The survey thus served a dual purpose of providing specific information to Pilio and gathering more general information about legal and organizational context for this research. The survey was delivered online using "survey monkey" and had 30 questions. The data gathered contributes to a developing database on the technical and legal infrastructure in small and medium enterprises. As sMeasure users are self-selected, this research design does not provide a representative sample of the entire population of the "minor league" area. Instead, it takes a snapshot of some unusual groups interested in improving the energy performance of their organizations.

Survey Results

We received 31 completed surveys from sMeasure users in 1 tourist/leisure facility, 3 schools, 12 arts facilities, and 15 church estates. Compared to the number of active sMeasure users, we estimate this is about a 9% response rate, which is typical for online surveys. The respondents are self-selected, so they represent a slice of sMeasure users, not the full spectrum.

[1] http://www.pilio-ltd.com/, tagline "Saving you energy, emissions, and money."

Thirty out of the 31 respondents classified themselves as from organizations with fewer than 150 employees, so they fit the EC definition of a small business or organization. However, some of these are affiliated with larger organizations, which raises the question of how independent these groups are. These issues are described in the case studies and will be discussed following the results. Respondents affiliated with more than one building were asked to answer the survey by choosing a “typical” building rather than responding generally across a broader set of premises.

The results are organized according to the three infrastructures explored in this paper: legal, organizational, and technical. In addition, a section on real time metering draws out respondent comments on this area, and a final section describes the two major respondent groups (arts facilities and church estates) as case studies that cross-cut these categories.

Ownership & Legal Infrastructure

Over 75% percent of the respondents said that they own or mostly own the premises their organization uses; the remainder were renters. Of the renters, most (77%) said they rent the whole premises, and 23% said they rent part of the premises. When renters were asked if they had contact with the landlord in relation to energy use, about 11% said they had frequent contact; and the remaining 89% had infrequent or little contact. When asked whether their leases allowed for modifications if deemed beneficial by both parties, 73% said their leases would allow for such modifications. However, 27% said they had no idea what their lease did or did not allow.

Energy Management Characteristics

About 40% of those surveyed said there was no formal or designated “energy manager” at the organization. Of these respondents, one third said there was a person who handled this responsibility in addition to a number of other duties. At two different organizations, the role of “energy manager” is filled by volunteers, rather than staffed by professionals. Five respondents said they play the role of energy manager for their organization (including the volunteers). A further 15 respondents (~50%) said there was an energy manager, but it is one person who handles this task as part of a larger job (65% total). Only one respondent said their energy manager had energy management as a sole responsibility. About 20% said there was a facilities team (not just an individual) inside the organization that handles building issues of all kinds. No respondents in this group were aware of a team outside the organization being hired to manage facilities or energy.

Although all the respondents are sMeasure users and therefore interested to some extent in energy use, 73% of survey respondents are not directly responsible for paying the energy bills. 21% are responsible for ensuring that someone else pays them; and 7% pay them directly. The respondents were asked if they had access to the energy bills (both gas and electric) for their organization, and 93% said they did have access, although two respondents clarified that this access was through other people (in one case, a treasurer; in the other, “only when I ask.”) In terms of billing payments, about 54% of respondents pay their bills directly to a supplier via direct debit; 27% organizations pay the supplier manually; and 4% say their costs are included in their rent. No respondents pay energy costs via a variable service charge levied by the landlord; however, about 15% said they were uncertain how the bills were actually paid.

Respondents were asked if their organizations were currently subject to any governmental regulations around energy use, such as the carbon reduction commitment (CRC)[2], energy performance certificates, or display energy certificates. 28% said their organizations were subject to these kinds of regulations; 62% said they were not; and 10% did not know. Five respondents mentioned DECs in their responses; one mentioned the CRC. When asked if their organization is concerned about energy use regulations likely to be implemented in the near future, no respondents were “very concerned.” Some were “somewhat concerned” (22%); most (63%) were neither concerned nor unconcerned. 15% said they were completely unconcerned by future regulations. Additional

[2] The Carbon Reduction Commitment (CRC) is designed to improve energy efficiency and cut emissions in large public and private sector organizations across the UK

comments regarding this suggested that energy concerns were based on organizational policies; price increases; increasingly bad weather; dilapidated buildings; and ancient boilers with obsolete parts. One respondent also commented that his/her organization had received a grant from the arts council related to energy savings, which raised awareness rather than increasing concern.

Technical Infrastructure

Respondents were asked a series of general questions about the type, number, and accessibility of electricity and gas meters on the premises, as well as whether or not the meters allowed automated meter reading (AMR). In addition, respondents were asked to submit photos of their meters. Results from these survey sections and the meter research are discussed below.

Electricity meters

When asked what kind of main electricity meter the organization had, 62% said their meters had a flashing LED; 23% had a mechanical meter with dials; and 12% had a meter with numerical characters. Only 28% of respondents had automated meter readings (AMR) from their meters; the remaining 72% did not have AMR. Of the respondents with AMR, only 1 respondent said they owned the data; three others could access the data through the supplier or a service contract that would allow free downloads of the data. Only about half of the organizations with AMR reported actually being able to access these data.

61% of the respondents said that their main meter was their only meter; 39% had more than one (ranging from 2 to 5 meters in total); no respondents indicated having any submetering in place.

Gas Meters

16% of respondents said they did not have a gas meter. The majority (52%) said they had a gas meter with characters only, and the next biggest proportion of respondents (24%) said they had a mechanical meter with dials. Only 8% (2 respondents) said they had a pulse-enabled meter, which would allow for AMR for gas. Of these, only one respondent actually has AMR for gas, but this respondent does not currently have access to the data. This respondent commented s/he will have access to the data “in future.” The vast majority of respondents (95%) do not have AMR for gas, and therefore do not have access to any data that AMR would provide.

64% have just one gas meter, and the remainder had between 2 and 4 meters. Two respondents each had one submeter for gas.

Meter photos

Meter photos for 27 buildings were submitted (see **Error! Hyperlink reference not valid.**), which were mostly theatre and church buildings. Between them, these buildings had 74 different meters of various kinds and capabilities.

Table 3. Organizations submitting meter photos

	Theatres	**Churches**	**Schools**	**Leisure**	**Total**
Elec (legacy)	0	6	4	0	**10**
Elec (AMR-ready)	14	10	2	2	**28**
Gas (legacy)	5	4	0	0	**9**
Gas (AMR-ready)	14	10	3	0	**27**
Total meters:	**33**	**30**	**9**	**2**	**74**

No. buildings	11	12	3	1	27

We classified meters into “legacy” and “AMR-ready” according to the types of measurements they are capable of making. A legacy electric meter, for example, has a dial or characters and can only be read manually. A legacy gas meter uses imperial units (cubic feet); newer AMR-ready gas meters are measured in metric units (cubic meters) and have a pulsed output that can be captured and read remotely. Figures 1-4 show some of the electricity and gas meter photos submitted by respondents. The black box with the wire coming out of it in Figure 4 is a device that shows this meter is AMR-enabled.

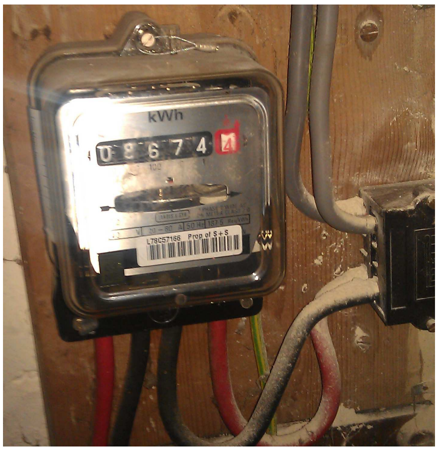

Figure 1. Legacy electricity meter

Figure 2. AMR electricity meter

Figure 3. Legacy gas meter

Figure 4. AMR gas meter

Interest in AMR and Real-Time Data

When asked about their interest in monitoring their energy usage (both gas and electricity), 71% said they would be interested in electricity real time data; 50% were interested in real time data for both electricity and gas. No respondents were interested in real time data for gas only. 29% of respondents were not interested in any kind of real time data.

Case Studies

In this section we combine expert knowledge from Pilio's executive director with survey results to provide a different view of the respondents that cross-cuts the survey questions and raises additional topics for further discussion. It focuses on the two main respondent groups: churches and theatres. Together, these respondents accounted for 87% of survey responses. When considered in their broader context, they present two very different sets of physical and organizational challenges.

Theatres (39% of responses)

The group of twelve arts facilities in the sample contains one micro business (four employees); seven small businesses (10-50 employees); three medium businesses (51-250 employees) and one behemoth with 2000+ employees. The giant in the sample is the largest theatre operator in the UK, running 39 venues across the country, including theatres in London's West End and regional theatres in cities from Torquay to Glasgow. The group employs 3,500 staff and produces hundreds of theatrical shows each year. Over the past two years the group has transformed its approach to dealing with its environmental impacts, cutting overnight energy use by 15% and bringing zero waste to landfill [18]. Although only one respondent answered on behalf of the large theatre group, nine of the other respondents also belong to this larger group, representing 83% of the theatre respondents. The survey was not designed to explore the relationship between pieces of an organization and the whole, but it raises some interesting energy management questions which will be discussed further in the next section.

The respondent who answered on behalf of the large theatre organization is the group's designated safety and environmental advisor. She was hired into this post in 2011 after managing a single theatre site for 12 years. As this is a relatively recent position, much of the group's environmental data was not readily available in a centralized or accurate format when she began her work. Her first job was to work with the utility broker to build up a comprehensive system of reporting. In 2012, she got a grant to upgrade the group's electricity meters. Now both she and the venue managers have half-hourly electrical meters and regular reports. She decided to target "overnight" usage because show producers hire the auditoriums for rehearsals and can use the space as they see fit during the day. Working with venue managers, she conducted site audits by torchlight to see what could be turned off at night. Her efforts resulted in a 15% energy use reduction that cut CRC costs by £6,000 a year. This year she plans to upgrade all the gas meters from manual readings to AMR and institute a training course on environmental impacts for the theatre operations staff.

Churches (48% of responses)

Compared to the theatre case study above, the Church of England faces a very different situation in terms of staffing and its building stock.

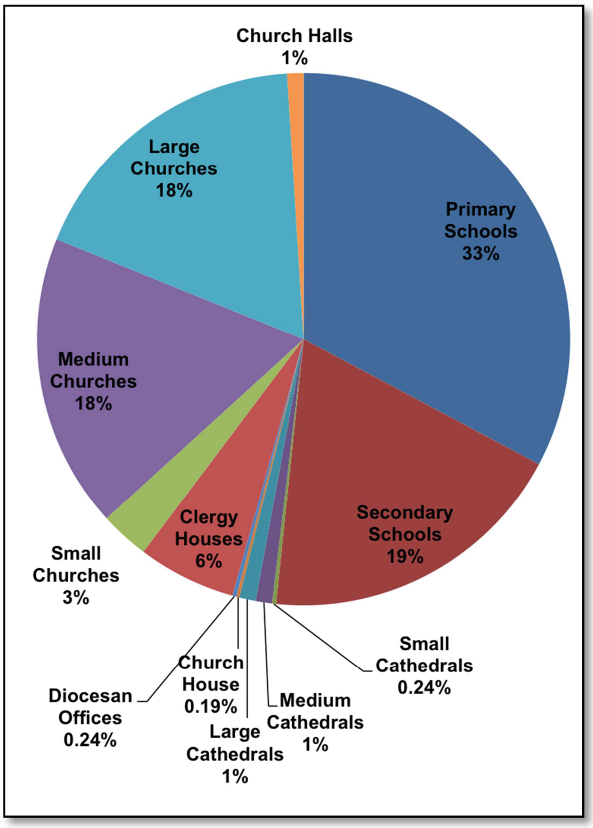

Figure 5. Church of England carbon emission % by building type.

The first question on the survey was "approximately how many people work for your organization?" which most respondents interpreted as a question about employment. Many church respondents started their response with "it's a church" and then tried to fit the organizational context to this question. Two respondents said no one worked for the church, although one then commented that the minister is paid. Many respondents mentioned the contribution of volunteers, and several mentioned the number of people in the congregation. These various responses suggest that in a non-profit, faith-based organization, the concept of "employment" or "work" is a slightly difficult one. However, all of these respondents noted that the staff positions in their churches are minimal. By the EC definition, all of the organizations are in the "micro" category with between zero and five employees. As with the theatre case, however, there was one respondent who spoke on behalf of the larger organization: the Church of England. This respondent indicated there are approximately 100 employees working with 834 churches and vicarages.

The Church of England estate is vast and covers about 16,000 buildings. According to a recent audit [19], it includes 42 cathedrals; 4,677 schools; and 15,779 churches. The Church has committed to a carbon reduction target of 80% by 2050, with an interim target of 42% by

2020 [20]. To achieve these commitments, the Church has implemented a program called “Shrinking the Footprint” to reduce its carbon emissions. However, participation in this program is voluntary and participation is low. Of the 430 buildings that have thus far registered (3% of the estate stock), only 78 (0.5%) contributed enough data to build the chart in .

These data suggest that the Church of England is confronted by an almost impossible situation. Their portfolio of buildings is a large, diverse, and old. Many of the properties are “listed” for their cultural and historic significance, which makes physical changes difficult. For example, stained glass windows are not designed for energy efficiency. Additionally, the metering infrastructure in the Church estate is meagre: only one respondent claimed to have access to AMR electricity data, compared to the theatre group which has AMR electricity meters across all sites and will soon also have AMR gas. Coupled with these challenges, the Church has a very small personnel resource upon which to depend, given that most of the staff are volunteers.

Discussion & Conclusions

We initiated the research envisioning a foray into a diverse set of building types, and found two big clusters of arts facilities and churches. We anticipated that the users of sMeasure would be data poor and that they would be mostly tenants rather than owners or landlords. Table 4 shows the results for our survey sample, mapped onto the segmentation typology articulated in an earlier section. While 71% of our survey respondents were indeed “data poor(er)”, 29% of them had AMR for electricity, so we have classified them as “data rich(er).” A far higher percentage of the respondents were owners (Types A and B) than we expected, only 21% classified themselves as renters (Types E and F). In our sample, about twice as many tenants and owners were “data poor” rather than “data rich.”

Table 4. Socio-technical segmentation of survey respondents

<table>
<tr><th colspan="2">Segmentation of the UK Non-Domestic Market</th><th>Data Rich(er)</th><th>Data Poor(er)</th><th>Totals:</th></tr>
<tr><td colspan="2">Owner Occupied</td><td>A (21%)</td><td>B (58%)</td><td>79%</td></tr>
<tr><td rowspan="2">Leased Space</td><td>Landlord</td><td>C</td><td>D</td><td>0%</td></tr>
<tr><td>Tenant</td><td>E (8%)</td><td>F (13%)</td><td>21%</td></tr>
<tr><td></td><td>Totals:</td><td>29%</td><td>71%</td><td></td></tr>
</table>

What we learned from the combination of the survey and the contextual knowledge of our partner Pilio was that more data isn’t necessarily better. Not all respondents aspired to be data rich: 29% had no interest in real-time data. Moreover, some “data rich” organizations are swamped by energy information and need better analysis of their data to lead to actionable insights. Where there is enough staff time and expertise to do data analysis (as with the large theatre group) the results of enriching a data stream can be significant. Although better data streams may be necessary for better energy management, they are not sufficient. Where there is not enough staff time and expertise to review the data, as with the Church of England, it is unlikely that better metering will lead to better energy management.

Although previous research has suggested that the size of an organization is a key factor in whether or and how it can adopt innovations [5, 8], we wonder whether organizations that have been studied previously were truly standalone SMEs or whether they may have been affiliated with part of a larger organization. Most of our theatre and church respondents answered organizational questions based on the smaller unit of their direct experience, rather than distinguishing their part as contributing to a larger whole. On its own, the survey data would not have revealed these important connections; seeing these relationships required a review of the data from someone knowledgeable about the participating organizations who could situate the responses in context. As other ongoing efforts attempt to gather information about the non-domestic stock on a building by building basis [2, 4], we argue that these efforts may need to take account of the connections between buildings and organizations which may be invisible to an energy and building lens. The poet John Donne once wrote that “no man is an island,” arguing for the importance of interconnection within humanity. It would be interesting to understand whether and how this concept is applicable to buildings and organizations in today’s world of membership, affiliation, aggregation, and social media. Indeed, some scholars have argued for the importance of communities that are built across and between buildings [10, 21].

Recommendations for Further Research

Although the challenges in improving the existing building stock are legally, organizationally, and technically complex, the data gathered here suggest that even the minor leagues are moving on these fronts in different ways. To assist these efforts, the paper emphasizes that further research is needed into (1) lease language, other governance structures, and social practices that can facilitate better cooperation between tenant and landlord, (2) the scope for energy management positions shared between small organizations, (3) low-cost “smart-er” meters that can be reversibly retrofitted onto existing electricity and gas meters, and (4) the combination of these areas.

Legal Infrastructure

Although the idea and language of green leases was largely unheard of in England before 2007, there are now a number of toolkits available, giving tips and precedent wording for inclusion in leases, such as the Green Lease Toolkit issued by London’s Better Building Partnership (BBP) [13, 22]. These leases (and also or alternatively, memorandums of understanding) aim to help landlords and tenant cooperate in the pursuit of more sustainable practices. Further empirical work in this area is needed to understand how these traditionally adversarial relationships are being reconstructed in a cooperative spirit [13, 21].

Energy Management

Where energy management “sits” within the staffing of an organization is an area that is poorly understood within the dominantly technical field of energy efficiency improvement. Our results suggest that organizations with a dedicated energy manager and smart meters will be more effective than smart meters alone. Given the fact that many organizations are too small to hire an in-house energy manager, it is possible that this role will be filled increasingly from outside the organization. Although no respondents indicated the presence of an external team dedicated to energy management at their organization, to some extent, this is the role that Pilio currently occupies. Further empirical work looking at how many energy managers it takes to change the building stock would be of use. The UK Engineering and Physical Sciences Research Council announced a call for research in this area in 2013, with results to be revealed in early 2014.

Technical Innovation

The results of our work and other research shows there is still a large stock of non-smart ‘legacy’ meters in use in the current building stock. Retrofitting these meters is with a combination of various technologies is one interesting area of research. Some innovators have attempted to retrofit these into half-hourly meters using time-lapse web-cams and onboard optical character recognition (OCR) software, but these have not been greatly successful. OCR is difficult for meters, cameras get moved, background light can interfere, and onboard software has problems. Some of these problems can be overcome by sending the images to cloud software on the internet for further processing, or including human recognition. Alternatively, small linux machines or Android phones can be used as local data monitors with powerful onboard processing and either Ethernet connection or wfi/3G dongle capability. These can be used to remotely read gas/oil/water pulsed meters, as well as electricity through a current clamp or flashing LEDs, and can also provide other information such as temperature.

Innovative Combinations

Although there is further research needed in each of the areas mentioned above, innovative combinations of these areas will likely yield the greatest levels of carbon reduction. From a program evaluation standpoint, this may be complicated, as it would be difficult to disentangle which part of the package is most effective and why. However, if the goal is improving energy efficiency, this exploratory study suggests these three interrelated areas require further attention, both separately and together.

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Commercial Sector Behavioural Energy Savings

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Abstract

Research on energy savings in businesses has been dominated by an engineering economics paradigm, in which economic agents adopt practices and technologies which are cost effective, typically as measured on a life cycle cost basis. This paper challenges this paradigm and reports on a detailed behavioral study done with business customers. Using data collected from an on-line survey of 628 business respondents, we develop and apply a conditions, capacity and commitment model of behaviour, which argues that conservation and energy efficiency adoption depend on the customer's satisfaction with and level of concern around energy efficiency (conditions), the customer's ability to act to change or modify service levels (capacity), and customer's undertaking or implementation of energy efficient actions or practices (commitment). Implementation of this model was based on a detailed survey which focused on four main uses of energy in businesses: indoor lighting, space heating, space cooling and personal computers. The study found that the most promising areas for behavioural energy change in business included turning lights off, use of day lighting, opening blinds in winter, reduce winter thermostat set points, opening windows in summer, closing blinds in summer, raising temperature set points in summer, enabling power management on personal computers, turning off all computer components, and turning of computer monitors.

Introduction

Research on energy conservation has been dominated by an engineering economics paradigm, in which agents adopt technologies and practices which are cost effective (Duke and Kammen (1999); Gorlove and Eto (1996), Horowitz and Haeri (2001); Jaffe and Stevens (1995); Joskow and Marron (1992). Analysis of opportunities typically proceeds by estimating life cycle costs and assuming that the technologies and practices with the best life cycle costs will be the ones adopted. The most effective conservation policy is the one which most cost effectively promotes improvements in lighting, appliances, motor systems, heating, ventilation, air conditioning and building shells. These conservation policies might include addressing market failures or market barriers or both, but the emphasis is on the underlying economics of the efficient technology compared to alternative technologies.

The behavioral literature on how customers actually make decisions on choice of energy using technologies and the use of these energy using technologies has had, until recently, relatively little impact on energy conservation policies (California Energy Commission (2003), Janda et al. (2002), Katvetz and Johnson (1987), Lutzenhiser (2002), Stern (2000). The situation began to change during and after the California energy crisis of 2000-2001, where traditional hardware solutions were initially promoted, but the substantial demand reductions actually observed appeared due largely to conservation behaviors promoted by social marketing. This suggest the need to re-examine the role of energy users in securing conservation benefits and to build a model to understand why some customers adopt energy conserving technologies and practices while others do not adopt them.

The objective of this paper is to report the results of a behavioral survey conducted with business clients. Using data collected from an on-line survey of 628 business respondents, we develop and apply a conditions, capacity and commitment model of behaviour, which argues that conservation and energy efficiency adoption depend on the customer's satisfaction with and level of concern around energy efficiency (conditions), the customer's ability to act to change or modify service levels (capacity), and customer's undertaking or implementation of energy efficient actions or practices (commitment). We examine four main end uses for electricity and natural gas: interior lighting, space heating, space cooling and personal computers.

Method, Data and Sample

Method

Two of the leading behavioral models in the field of social psychology are the theory of reasoned action and the theory of planned behavior. The theory of reasoned action was developed by Fishbein and Ajzen (Fishbein and Ajzen (1975)] in response to a widespread view that traditional attitude-behavior research in social psychology had reached an impasse because correlations between attitude measures and performance of voluntary behaviors were often weak. Fishbein and Ajzen argued that if a person intends to undertake a behavior, then she is likely to do it and that, furthermore, her intentions are conditioned by her attitudes towards the behavior and her assessment of social norms. In other words, performing a voluntary action is a function of intention and intention is a function of both attitudes and of social norms. The model has been widely applied, particularly to consumer behavior and in health-related fields.

A number of studies have found high correlations between attitudes and behavioral intentions and between subjective norms and behavioral intentions, which would appear to provide evidence in support of the theory of reasoned action. However, some studies have shown that behavioral intent is not necessarily translated into behavioral action, so that behavioral intent cannot be the sole determinant of behavior. Ajzen (1985) introduced the additional factor of perceived behavioral control into a revised model which he called the theory of planned behavior. Detailed meta-analysis demonstrated that this additional factor often helps to explain the relationship between behavioral intent and actual behavior. More recently, a number of studies have emphasized the importance of focusing on behavioral attributes rather than behavioral domains. Behavioral attributes refer to the particular characteristics that make up the behavioral domain. For example, the attributes that make up the behavioral domain of energy efficient lighting might include current light levels, desired lighting levels, ability to control lighting levels, and concerns with the environmental impacts of energy use.

Our model builds on the theory of planned action literature and argues that adoption of conservation and energy efficiency actions and practices depends on three main factors – conditions, capacity and commitment – and our model further defines behavioural target as the remaining potential. (1) Conditions surrounding a respondent's potential conservation action, which may include attitudes towards energy use or the respondent's evaluation of satisfaction with the status quo, or her evaluation of actual conditions compared to expected norms. Conditions can be thought of as including attitudes and norms. (2) Respondent's capacity to act, which may include the presence of an enabling technology and/or the authority to act. Capacity can be thought of as including ability and authority. (3) Respondent's commitment to act by undertaking the energy efficient action or behavior, which might be conditioned on the frequency with which an action has been performed in the past. Finally, we define (4) Behavioural Target or the remaining potential is the difference between capacity and commitment. So the key relationship in our analysis is:

Behavioural target = Capacity – Commitment.

Data and Sample

The conditions-capacity-commitment model is applied here to four main business energy end use areas: indoor lighting; air conditioning; space heating and personal computers. Data was collected through a web-based survey of 628 business respondents. The survey included a wide range of energy related attitudes, condition and behaviors as well as detailed information on the respondent's place of work. For each end use area, the respondents were asked a series of scaled questions dealing with their level of concern about the service level for the end use (such as lighting levels or temperatures); their ability to modify or change service levels; and the extent to which they performed energy efficient actions or behaviors.

This study examines four main issues. (1) Lighting Behavior. Understand appropriateness of lighting levels, ability to use lighting conservation actions (turn lights off, use day lighting, use task lighting) and frequency of use of efficient lighting actions. (2) Air Conditioning Behavior. Understand appropriateness of cooling levels, ability to use cooling conservation actions (open windows, close blinds, turn temperature up) and frequency of use of efficient cooling actions. (3) Space Heating Behavior. Understand appropriateness of heating levels, ability to use heating conservation actions (open blinds, turn down temperature, close the exterior doors) and frequency of use of efficient heating actions. (4) Personal Computers. Understand incidence of personal computer use at work, ability to use heating conservation actions (power management enabled, turn off all computer components, turn of computer monitor) and frequency of use efficient computer use actions.

Because the information for this study came from an on-line panel, we wanted to understand if the sample was reasonably representative of the population. Table 1 compares some key demographic characteristics of the study sample with the Residential End Use Survey (REUS), which was weighted to accurately reflect the demographics of the population. The study sample is more highly educated than the population, the number of people in the home is similar for the two samples, and the household income of the study sample is somewhat higher than the population. Given that the survey sample is of respondents who are in the labour force, while the REUS sample includes both individuals in the labour force and those not in the labour force, the survey sample is probably reasonably representative of the population.

Table 1. Sample and Population Characteristics

Characteristic	Survey sample	REUS
Education: college or university graduate	57%	47%
Household composition: number in home	2.6	2.5
Household income: $60 K or more	61%	49%

Results

Indoor Lighting

Table 2 summarizes the 2010 survey information on indoor lighting conditions, capacity, commitment and behavioural target. We first asked survey respondents how they would describe the amount of light in their current work environment: is it about right, too dim or too bright? About 79% of survey respondents indicated that lighting conditions were about right. These respondents may have limited intrinsic motivation to change their lighting use behaviour.

Table 2. Indoor Lighting Conditions, Capacity, Commitment and Behavioural Target

	Conditions	Capacity	Commitment	Behavioural target
Turn lights off	79%	80%	40%	40%
Day lighting	79%	76%	41%	35%
Task lighting	79%	37%	31%	6%

Survey respondents were asked a series of questions about activities related to turning lights off. They were first asked if they were able to turn off or eliminate some of the unnecessary lighting. About 80% of respondents indicated that they had the ability to turn off or eliminate unnecessary lighting while 20% of respondents indicated that they did not have this ability. Those respondents who had the capacity to turn lights off were asked whether they turned off (unneeded) lights always, often, sometimes or never. About 40% of respondents indicated that they turned off their unneeded lights always or usually, while 40% of respondents indicated that they turned off their unneeded lights occasionally or never. Thus 40% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to day lighting. They were first asked if they were able to make use of day lighting. About 76% of respondents indicated that they were able to use day lighting while 24% of respondents indicated that they did not have this ability. Those respondents who had the capacity to use day lighting were asked whether they made use of day lighting always, often, sometimes or never. About 41% of respondents indicated that they made use of day lighting always or usually, while 35% of respondents indicated that they made use of day lighting occasionally or never. Thus 35% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to task lighting. They were first asked if task lighting was available. About 37% of respondents indicated that they task lighting was available while 63% of respondents indicated that task lighting was not available. Those respondents who indicated that task lighting was available were asked whether they used task lighting always, often, sometimes or never. About 31% of respondents indicated that they use task lighting always or usually, while 6% of respondents indicated that they used task lighting occasionally or never. Thus 6% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Space Heating

Table 3 summarizes the 2010 survey information on space heating conditions, capacity, commitment and behavioural target. We first asked survey respondents how they would describe the appropriateness of winter temperature levels in their current work environment: are temperatures about right, too hot or too cold? About 52% of survey respondents indicated that winter temperature conditions were about right. These respondents may have limited intrinsic motivation to change their space heating use behaviour.

Table 3. Space Heating Conditions, Capacity, Commitment and Behavioural Target

	Conditions	Capacity	Commitment	Behavioural target
Open blinds	52%	67%	49%	18%
Reduce temperature	52%	21%	10%	11%
Close exterior doors	52%	85%	75%	10%

Survey respondents were asked a series of questions about activities related to space heating. They were first asked if they were able to open blinds. About 67% of respondents indicated that they had the capacity to open blinds while 33% of respondents indicated that they did not have this capacity. Those respondents who had the capacity to open blinds were asked whether they opened blinds in winter always, often, sometimes or never. About 49% of respondents indicated that they opened the blinds in winter always or usually, while 18% of respondents indicated that they opened the blinds in winter occasionally or never. Thus 18% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to reducing temperature set points in winter. They were first asked if they were able to make use of temperature set back. About 21% of respondents indicated that they were able to use temperature set back while 79% of respondents indicated that they did not have this ability. Those respondents who had the capacity to set back temperature were asked whether they made use of temperature set back always, often, sometimes or never. About 10% of respondents indicated that they made use of temperature set back always or usually, while 11% of respondents indicated that they made use of temperature set back occasionally or never. Thus 11% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to closing exterior doors in winter. They were first asked if any of the doors at the workplace were used for public access. About 85% of respondents indicated that some doors in the workplace were used for public access, while 15% of respondents indicated that there were no public access doors. Those respondents who indicated that there was public access through external doors were asked whether they ensured that these doors were closed always, often, sometimes or never. About 75% of respondents indicated that they ensured that these doors were closed always or usually, while 10% of respondents indicated that they ensured that these doors were closed occasionally or never. Thus 10% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Space Cooling

Table 4 summarizes the 2010 survey information on space cooling conditions, capacity, commitment and behavioural target. We first asked survey respondents how they would describe the appropriateness of summer temperature levels in their current work environment: are temperatures about right, too hot or too cold? About 49% of survey respondents indicated that summer temperature conditions were about right. These respondents may have limited intrinsic motivation to change their space cooling use behaviour.

Table 4. Space Cooling Conditions, Capacity, Commitment and Behavioural Target

	Conditions	Capacity	Commitment	Behavioural target
Open windows	49%	36%	25%	11%
Close blinds	49%	67%	39%	28%
Raise temperature	49%	21%	11%	10%

Survey respondents were asked a series of questions about activities related to opening windows in the summer. They were first asked if they were able to open windows. About 36% of respondents indicated that they had the ability to open windows while 74% of respondents indicated that they did not have this ability. Those respondents who had the capacity to open windows were asked whether opened windows always, often, sometimes or never in the summer. About 25% of respondents indicated that they opened windows always or usually, while 11% of respondents indicated that they opened windows occasionally or never. Thus 11% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to closing blinds in summer. They were first asked if they were able to make use of blind closing. About 67% of respondents indicated that they were able to close blinds while 33% of respondents indicated that they did not have this ability. Those respondents who had the capacity to close blinds were asked whether they closed the blinds in the summer always, often, sometimes or never. About 39% of respondents indicated that they made use of blind closing always or usually, while 28% of respondents indicated that they made use of blind closing occasionally or never. Thus 28% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to raising set point temperatures in summer. They were first asked if temperature set back was available. About 21% of respondents indicated that they temperature set back was available while 79% of respondents indicated that temperature set back was not available. Those respondents who indicated that temperature set back was available were asked whether they used temperature set back in summer always, often, sometimes or never. About 11% of respondents indicated that they used increased temperature set points in summer always or usually, while 10% of respondents indicated that they used increased temperature set points in summer occasionally or never. Thus 10% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Personal Computers

Table 5 summarizes the 2010 survey information on use of personal computers in the workplace. We first asked survey respondents if they used computers in the workplace. About 79% of survey respondents indicated that they used personal computers in the workplace. One reviewer noted that personal computers and related equipment in businesses are frequently configure as part of a network, which may limit the ability or individual users to modify energy use. This issue would be worth pursuing in future surveys.

Table 5. Personal Computers Conditions, Capacity, Commitment and Behavioural Target

	Conditions	Capacity	Commitment	Behavioural target
Power management enabled	79%	73%	62%	11%
Turn off all components	79%	79%	39%	40%
Turn off computer monitor	79%	79%	36%	43%

Survey respondents were asked a series of questions about activities related to power management of their personal computer at work. Power management was defined as follows: "when you are away from your computer during the day, is it pre-set to go into a power saving mode or sleep mode after not being used for a few minutes?" They were first asked if they were able to use power management. About 73% of respondents indicated that they had the ability to use power management while 27% of respondents indicated that they did not have this ability. Those respondents who had the capacity to use power management were asked whether they used this feature always, often, sometimes or never. About 62% of respondents indicated that they used power management mode always or usually, while 11% of respondents indicated that they used power management mode occasionally or never. Thus 11% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to turning off all computer components. They were first asked if they were able to turn off all computer components. About 79% of respondents indicated that they were able to turn off all computer components (that is, all those who used a personal computer at work were of course able to turn off all components), while 21% of respondents indicated that they did not have this ability (because they did not use a personal computer at work). Those respondents who had the capacity to turn off all computer components were asked if they did this always, often, sometimes or never. About 39% of respondents indicated that they turned of all components always or usually, while 40% of respondents indicated that they turned of all components occasionally or never. Thus 40% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Survey respondents were asked a series of questions about activities related to turning off just the computer monitor. About 79% of respondents indicated that they had the ability to turn off a computer monitor while 21% of respondents indicated that they did not have the ability to turn off a computer monitor (since they did not have one at work). Those respondents who indicated that turning off a computer monitor were asked whether they did this always, often, sometimes or never. About 36% of respondents indicated that they turned off a computer monitor always or usually, while 43% of respondents indicated that they turned off a computer monitor occasionally or never. Thus 43% of respondents are the target for behavioral change since they have the capacity to perform this action, but they do this only occasionally or never.

Conclusions

Research on energy savings in businesses has been dominated by an engineering economics paradigm, in which economic agents adopt practices and technologies which are cost effective, typically as measured on a life cycle cost basis. This paper challenges this paradigm and reports on a detailed behavioral study done with business customers. The objective of this paper is to report the results of behavioral surveys conducted with business clients using a panel approach to data collection and analysis. Using data collected from an on-line survey of 628 business respondents, we develop and apply a conditions, capacity and commitment model of behaviour, which argues that conservation and energy efficiency adoption depend on the customer's satisfaction with and level of concern around energy efficiency (conditions), the customer's ability to act to change or modify service levels (capacity), and customer's undertaking or implementation of energy efficient actions or practices (commitment).

The implementation of the model used detailed surveys and focused on the main business energy end uses, including lighting, air conditioning, space heating and personal computers. For each end use area, respondents were asked a series of scaled questions dealing with their satisfaction with service levels for the end use (such as lighting levels or temperatures); their ability to modify or change service levels (such as local on/off switches or HVAC controls); and the extent to which they performed energy efficient actions or behaviors (three possible actions for each end use). The study found that the most promising areas for behavioural energy change in business included turning lights off, use of day lighting, opening blinds in winter, reduce winter thermostat set points, opening windows in summer, closing blinds in summer, raising temperature set points in summer, enabling power management on personal computers, turning off all computer components, and turning of computer monitors.

The approach used here appears to be unique among studies of energy use in commercial buildings, in that it is based on a detailed survey of business customers, but it is related to some building simulation studies of commercial building energy use. Hoes (2008) examines the impact of user behavior in simulations of five case study buildings. Soebarto and Williamson (1999) argue that differences between assumed and actual energy use can be quite large, and that these differences are due in part to occupant behavior. Degelman (1999) notes that although thermal processes have become much more efficient over the past forty years, user behavior has a greater influence on building energy performance than does the characteristics of the building façade or envelope. Rijal et al (2007) claim that using more sophisticated models of user behavior will lead to better understanding of building-occupant interactions and lead to improved building design from an energy use perspective. Future work could usefully use the survey based approach applied in the present study to inform improved building energy use simulation models.

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Software Engineering for Building Energy Efficiency

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Abstract

Modeling of building energy use provides an interesting set of challenges, whereby seemingly incompatible concepts such as energy flows, management structures, and the human in the loop must be accounted for. Good software design underpins the design of building controls, whereby data flows, control hierarchies, and data documentation must be understood to provide a reliable product, notably to provide risk management in coding. The same techniques can also be used to apply energy analysis techniques to energy efficiency in buildings. Thus we may also take into account qualitative data such as human factors, showing that the same techniques used for software design enable us to more clearly understand the interdependencies in building energy and resource use.
The paper is split into two sections. Firstly we discuss the advantages of a variant of dataflow diagrams to model energy and resource flows in a commercial building,
Secondly, we suggest a complete energy analysis method. This guides the energy practitioner with a logical progression through the standard Energy Analysis Techniques from benchmarking, through regression to Cusum, to energy profile analysis, to guide in building energy pathology and to make energy saving recommendations.

Keywords: Energy, Regression, Cusum, Dataflow, Flow, Chart, Method

Introduction

Energy savings through application of energy analysis techniques offer powerful opportunities for making quick savings; harvesting the 'low hanging fruit': In the UK, 44% of energy is used as part of activities in buildings [1]. One significant waste of energy is through inadequate control of building services, compounded by the time delay introduced before faults are rectified, if they are rectified at all. Human intervention is needed to maintain these controls, which tends to be reactive. The amount of energy which could be saved through improving (maintaining) building controls varies with the fault in question, although tends to fall in the range 10-30% of non fault condition consumption [2,3]. Advanced metering, which gathers building energy data (usually gas, electricity and district heat) remotely (typically half-hourly), is becoming much more widespread [6]. It is mainly used for accurate and timely billing, although also offers very useful datasets to study energy use patterns [3,5,6]. Early data analysis strongly suggests that much energy can be wasted due to building controls not working properly [3] causing building services to run unnecessarily (e.g. over-cooling, unoccupied heating). Root causes include systems which are becoming too complex for on-site staff to manage effectively and are poorly documented, inadequate initial commissioning [7], uncertainty about what areas or equipment is on a particular meter (notably in older buildings), and equipment failures. If half-hourly data analysis could be used to detect these problems quickly if a combination of appropriate techniques are used [8]. Most analysis is relatively crude, looking for exceptions from historic behaviour or visual analysis of graphs in spreadsheets. These can identify gross and sudden faults but often fail to miss more subtle ones such as a slowly increasing base-load, and the majority of organisations do not have the skills or resources for even this level of analysis.
Research has identified numerous areas for energy conservation, which can enable us to meet Kyoto targets, and recent technical developments provide enabling technologies (hardware) for energy billing, in building control systems [9], automatic detection of energy waste [10], or building energy failure modes [3], notably advanced metering and radio telemetry. Potential for quick savings in electricity consumption have been identified [11], where out of hours switch off rates for IT can be as low as 30%. In the UK, unoccupied office lighting can amount for up to 23 – 30% of use in some areas, and was estimated by extrapolating from London profiles to the UK, to amount to 1500 - 1900 GWh electricity, or 0.8 – 1.1 MT CO_2 per year [2]. In similar work, incidents of heating of unoccupied non-domestic buildings at night and at weekends, were found to be as high as 30% [3]. This research also showed electrical base-loads to be increasing annually at a rate of 9%, and similar work has identified IT related base-loads as high as 40% of the daily peak [8]. Another example of easily avoidable energy waste is illustrated in a survey of around 700 retail premises, where very basic energy-saving measures for retention of heated air (closed doors, air curtains) were found in only 68.4% of buildings examined, and for cooling the figure was 39% [12]. These are typical examples of energy waste which may remain undetected for long periods. Techniques such as benchmarking [13], regression analysis, Cusum analysis [14] and energy profile analysis are useful parts of any building energy manager's tool kit. However, with the advent of high frequency profile data, an opportunity has arisen for a method of energy analysis which links together all of the currently used analysis techniques, and provides optimal chances to carry out building pathology and make energy saving recommendations, feeding into an

overall energy management strategy [15]. Circuit diagrams exist for plant, building, zone level analysis of energy flows, although typically useful mainly to electrical, electromechanical, or building services Engineers. Established standards exist for these. For higher level abstraction, the energy transfer diagram is a potentially more useful but more imprecise concept, whereby systems and components may be represented as graphics, which are frequently clear, informative, and user friendly to a non-technical audience, although literature on the evolution of the concept is sparse indeed. The point was recently made that development of ontologies for agent based modelling can be done in such a way as to improve information flow between interested parties, including for socio-technical data [16]. Creating such an ontological basis for representing energy use encourages precise and clear definition of both parameters of consuming entities and flows between them, which could have application beyond agent based modelling. This also raises the idea of modelling behaviour and other qualitative data in energy [management] models, for example including feedback loops for staff training and switch-off campaigns. Similarly, in the early stages of the KAP (Knowledge, Awareness, prediction) Project [17], the authors explored the graphical depiction of qualitative and quantitative factors in energy use. Figure 2, for example, was prepared as a part of a thought experiment as part of the project in response to conditions for food factory workers in the UK, notably on the importance of daylighting, which is an important part of workplace health and well being, and given a higher priority in mainland EU.

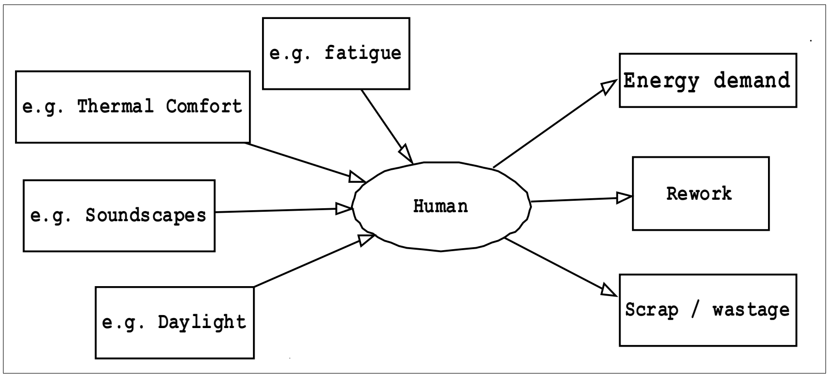

Figure 2 Flow diagram of input factors through a human worker where, in combination with the workers' own characteristics, they affect outputs.

For the modelling of energy flows, indeed the methods of examining these flows, we have yet to reach much of a unified approach, in terms of the compatibility of methods employed, and to bridge the gaps between modelling technical building services, energy hungry processes, and thermal comfort [18]. The disparate ways of representing energy use, from pinch diagrams, through to Sankey diagrams, all have established uses, and have been highly effective. A good example of using what a control Engineer would describe as a modified block diagram approach, combined with colour coding for various energy types, was demonstrated in [19]. The authors didn't stop at energy flows however, and successfully represented (modelled) material and resource flows.

We suggest that standard software Engineering techniques, a few of which we have highlighted, can be used to provide a helpful layer of abstraction above basic plant and circuitry, as an additional tool for analysis in itself, and as a way of guiding practitioners through this analysis. It becomes clear that some techniques from Software Engineering, where diagrammatic representation of complex and unwieldy systems is routine, may offer some as yet under explored insights into the energy analysis method.

Modeling of complex energy interdependencies

In Software design, it is fairly standard practice begin with a context model, which defines the inputs and outputs to a system [20]. In the case of a data system for balance enquiries on an ATM machine, for example, a customer code and authentication would be an input, a bank balance level as an input, a receipt and a figure for balance on a display screen and a log of the enquiry made as an output. We can see that the context level modelling approach can equally apply to energy flows within a building, indeed, resources too. An example is given below [figure 3] for energy flows into and from a carbon positive manufacturing building at context level, for three future scenarios.

A data flow diagram represents graphically the flow of data through an information system [21], and an adapted version can be used to model energy flows. It is common practice to expand the representation of a system at context level , which merely shows the interaction of a system with it's surroundings, using a data flow diagram. Figure 4, shows an example sub-diagram based on the 'process now' context model from figure 3.

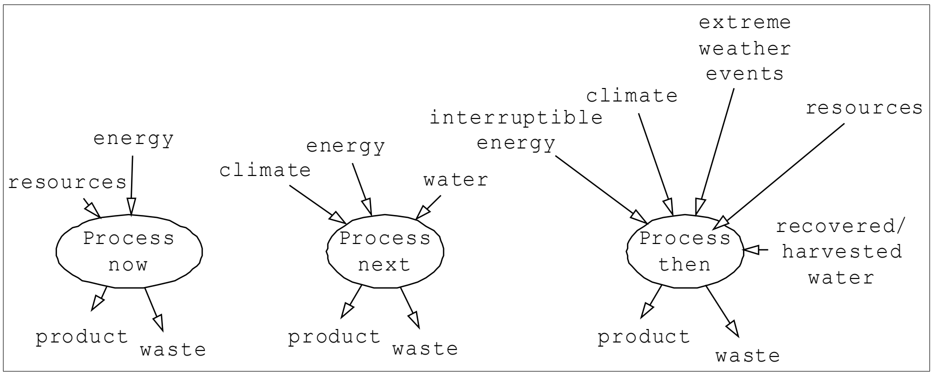

Figure 3 – Three future scenario Context diagrams for a manufacturing building

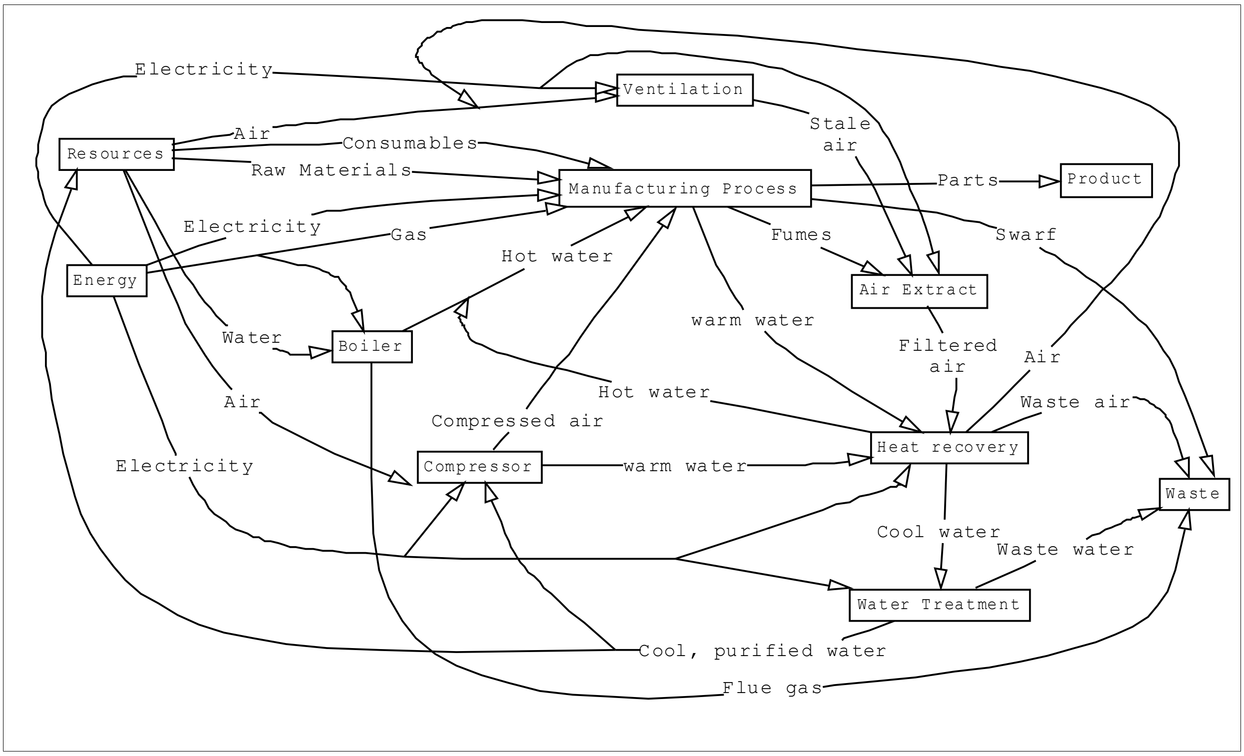

Figure 4. Internal resource and energy flows for the first scenario

Should such a diagram be used to represent a design for software, it is likely that data types would be used as labels for inter-connectors, and what these data would contain (for example, meter ID, int16 might refer to a 16 digit meter number as part of a smart metering system). The advantages of representing energy flows in the same way as data are numerous:

1. Firstly, complexities can be managed more easily, with 'drilling down' possible within individual operational blocks to describe more complex energy flows as separate sub-graphs.
2. Secondly, in the case of energy efficiency, freed the complexities of piping or wiring circuit diagrams, opportunities for e.g. heat recovery may also be seen more clearly.
3. Thirdly, we have a more user friendly approach which may cross boundaries between e.g. electro – electro-mechanical, building services, control engineering standards of diagramming [22].

The Energy Analysis method

As well as representing the energy characteristics and flows themselves using software engineering techniques, the energy analysis process as a whole may be modelled effectively in this way.he method presented was developed to assist the understanding and application of an MSc course module in Energy Analysis Techniques, as students would struggle to find a way to logically progress from one analysis technique to another. The challenge after defining the structure of energy analysis techniques is therefore to establish the progression between them, depending on conditions. The overall structure of Energy Analysis can be defined in a similar way to a Software Structure Chart – the example below in figure 5, has further annotations to describe individual techniques, and we would hope that this minor bending of the rules is taken in good faith. We describe below the steps undertaken to explore the range of energy analysis options available using software engineering diagramming techniques. The description serves both to illustrate our proposed application of the diagrams and to highlight the difficulty that would be faced if trying to describe the process with text alone. The text describes the content of dataflow diagram 6

With usual caveats on accuracy of data, a useful next step is benchmarking, to compare kWh/m^2 for gas and electricity (or other fuel) with comparable buildings. Should a building fall well within acceptable limits, this is not necessarily a reason to stop looking for further energy savings, many of which could offer short term or instant payback, and interventions such as switch-off campaigns, will still need to be repeated periodically.

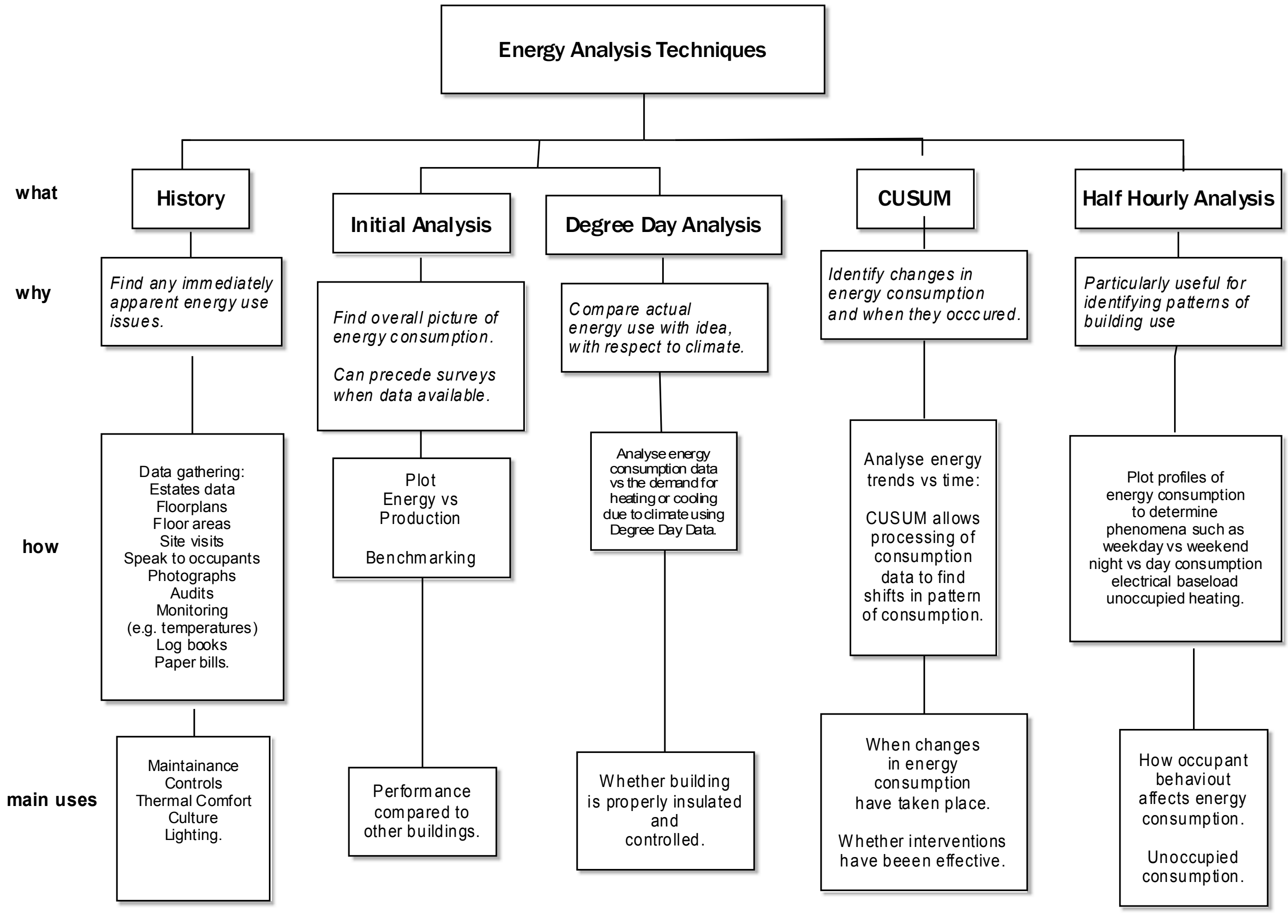

Figure 5 – Structure Chart Variant for Energy Analysis Techniques

Regression analysis is a useful tool for comparing the actual energy use with predicted energy use [14]. For example, a typical regression may plot predicted loads from production (e.g. GWh/t), or degree days, and so forth, against the actual load. From this, phenomena such as base-loads can be identified, the goodness of fit to a straight line in the form $y=mx + c$ (a polynomial may also be used) gives a good indication of the efficacy, or otherwise, of process or heating (or cooling) controls. Joining points together sometimes reveals a series of interconnected loops, which is a good indication of hysteresis. Perhaps the best example of such a phenomenon would be unauthorised adjustment of heating controls in the middle of the heating season, leading to a path of energy use as degree days reduce, which follows above the line defined by the regression model. Other phenomena identifiable include stratification, heating and cooling running simultaneously, under-heating and over-heating. The efficiency of an industrial process may also be determined through regression. In terms of representing regression in the manner of a software process, regression analysis can identify a plethora of energy related failure modes, represented as outputs to the process. These include:

1. Loose control (including dead-bands, poor accuracy and precision)
2. Incorrect zoning (e.g. A/C and Heating overlap)
3. Stratification
4. Hysteresis
5. Base-load
6. Poor overall efficiency
7. Under heating / cooling

Cusum, or cumulative sum analysis, is used to track cumulative deviations in energy performance from the regression model. In practice, this can be used to detect changes in the pattern of energy use. The logical link to energy profile analysis is missing in many practitioner's guides, and this is where software engineering style modelling of the energy analysis process becomes useful. Should energy use deviate rapidly away from the expected relation y=mx+c, and then deviate back towards it, we are using more energy than expected, and then less energy than expected, based upon all available data used for the regression model. We may therefore define this change in direction as an event. Usually it is then possible to see a change in energy profiles. Bearing in mind the Nyquist Sampling Theorem, half-hourly data may capture hour long events at the highest resolution. Many commercial buildings roughly follow periodic energy use over seven days, therefore to capture events, a profile of two weeks is useful, three is better. However, comparing energy profiles averaged over longer periods may lead to excessive profile smoothing, and consequent loss of detail. Therefore it makes sense to plot energy profiles after Cusum analysis, before and after each Cusum Event.

Cusum analysis may identify events, but the more nuanced use of Cusum allows rebasing – in this we define a period of time with known variables as normal, and are able to forecast or back-cast to see if energy savings have been made. Another extension of the Cusum method is where energy use between identified changes are a known quantity, we may draft a control chart, a robust method of finding deviations in energy use taking into account variations in the plant model. Thus, the Cusum process takes gas and electricity consumption data as its input, and outputs events and, potentially, baselining data.

The last technique considered is application of time-series data analysis directly to energy profiles. There are a number of extant time-series techniques that could be employed (fourier analysis, wavelet transforms, event detection algorithms). Space does not allow for a detailed discussion of all the techniques available, but they may be represented generically for the purposes of this illustration. Again inputs are quasi-real time consumption data. Four energy failure modes in energy use [3] are easily identifiable using high frequency data on energy profiles, usually applying to fuel use (e.g. half hourly data or sub-half-hourly gas) and are listed below. These form the outputs to the profile analysis process.

1. Heating (or cooling) out of season
2. Unoccupied Heating
3. High Base-load (also for electricity)
4. Heating constantly on

Figure 6 below, shows a sample data flow diagram for the energy analysis process.

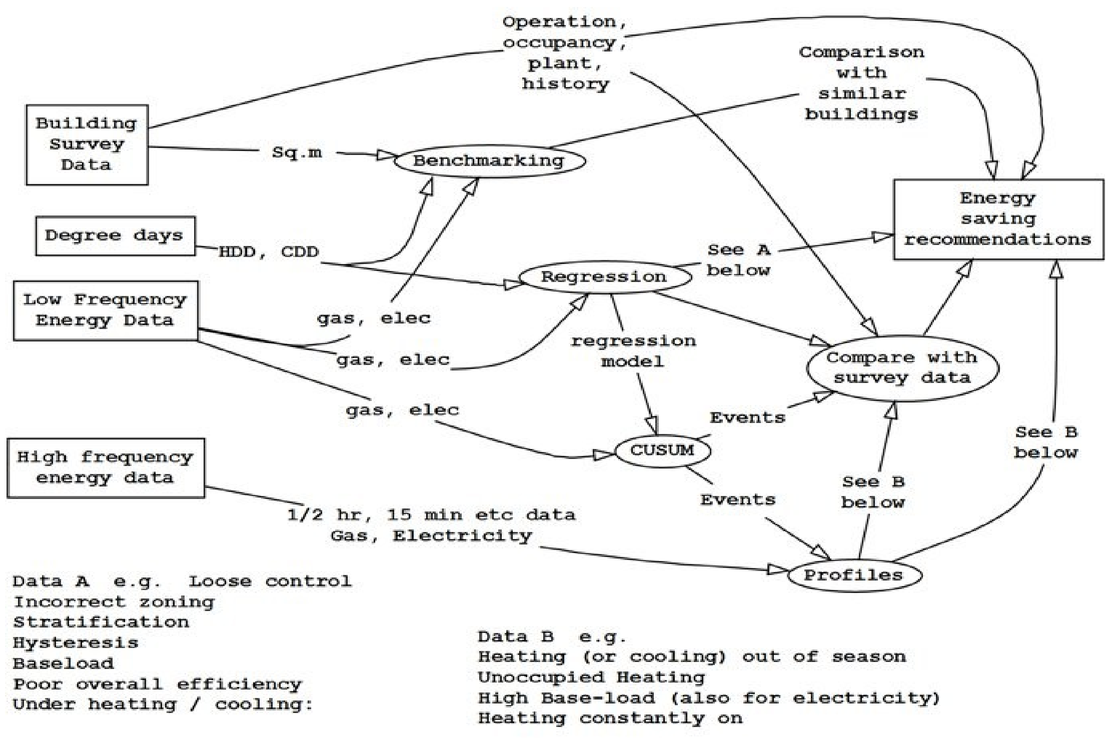

Figure 6. data flows for Energy Analysis Techniques

A minor shortcut has been taken in that a context diagram should normally be produced first, although in this case the logical leap is relatively small. In practice, flows may be slightly different depending on which stage of data gathering is used to port data to the process; e.g. A database query may extract half-hourly data, but may run more quickly to produce daily or weekly summaries, which may also be more compatible with locally available degree day data (should this not be derived by the Analyst from outside air temperature data). We start to see that the complexities of data-flows can be described fairly easily as a data flow diagram for energy analysis, which suggests a practical process model may be designed for practitioners in energy surveying and analysis. The result of a suggested method is shown in figure 7.

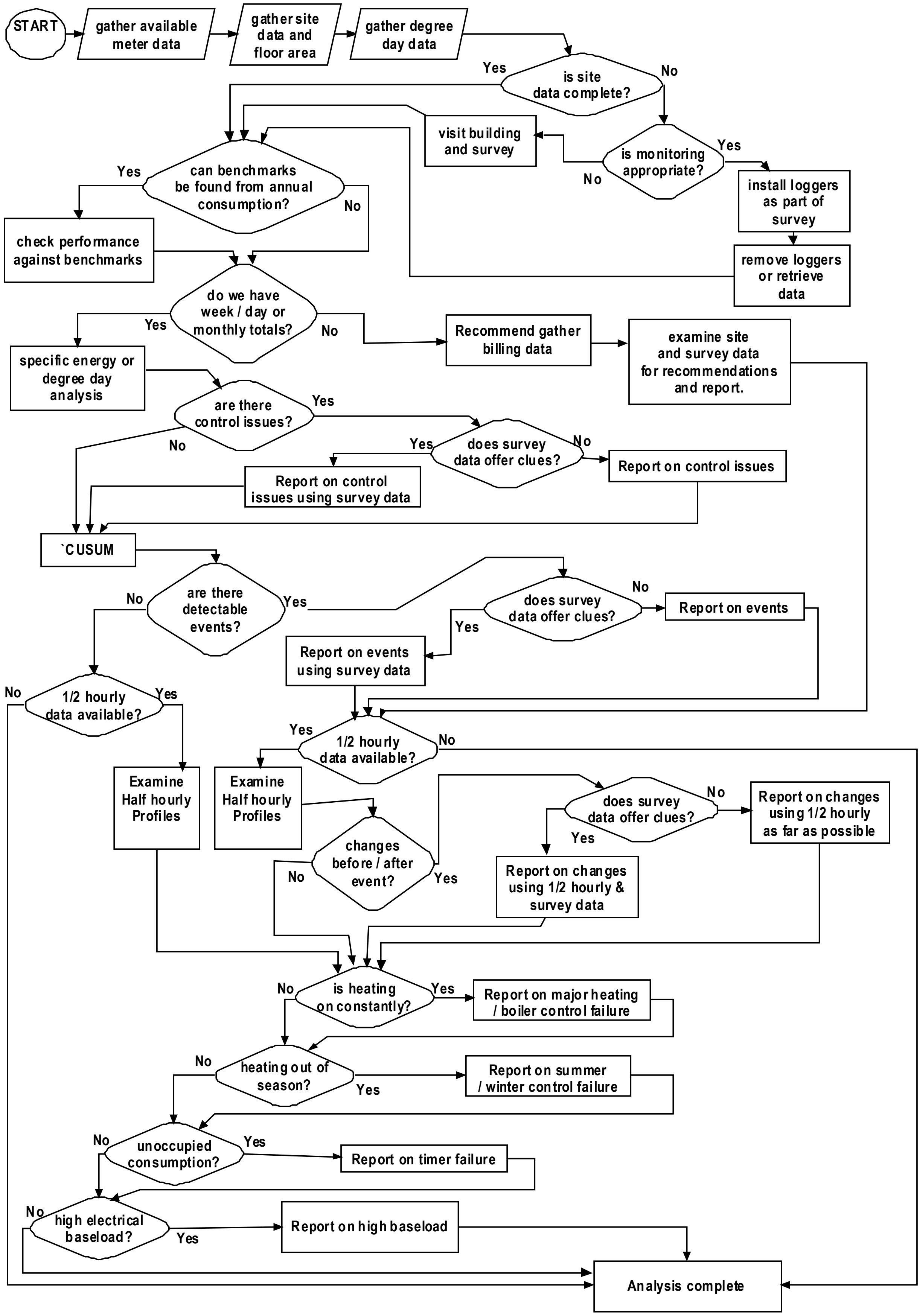

Figure 7. The Energy Analysis Method

Further developments and application

The method for describing energy flows described here has underpinned the proposal of an Energy Data Standard, as published by the authors [23], which enabled a breakdown of energy data types and supporting data for standardisation. These can be summarised as:

Temporal Data, such as Date formats, time stamping and sample rates. These data are vital to energy analysis, but often error prone. The conclusion from data structure analysis was that a minimum acceptable data quality level should be stipulated, and where substitution or interpolation are employed, documentation should be included. In addition, basic reliability metrics for telemetry systems should be documented.
Accuracy and Precision of energy data must be stipulated, including, for example, characteristics of transducers for energy use and environmental sensing.
Operational documentation is needed to drive energy analysis – this is concerned with data management as opposed to building documentation.
Finally, data documentation should be included in an energy database, not separately. This would include, for example, conversion factors to kWh.

These recommendations have been presented to the British Standards Institution as a standard proposal in 2013, as an output from the KAP project [17], and are under consideration for a standard at the time of writing The work continues at IESD, using these techniques to improve the robustness of the data model.

The Energy Analysis method has been offered as an option for a framework for coursework production to Masters Students in Energy Analysis Techniques, which teaches the fundamentals of energy management and energy efficiency. This is a core module to three MSc courses in Energy and Sustainable Building Design, Climate Change and Sustainable Development, and Energy and Industrial Sustainability, all at IESD. Currently a cohort of over 250 over three years have been given a chance to study the method, and almost all have adopted the approach for producing energy audit reports, analysing two each from a changing choice of 12 non-domestic buildings. A raft of energy audit reports have been produced, making energy saving recommendations. Generally it is found that a mixture of zero, short, medium and higher cost energy saving measures can be found for almost any commercial building, using a mixture of survey data and energy use data, with rapid savings with minimal outlay (such as BMS programming) possible being in the order of 30% of measures proposed. A subsequent journal article will evaluate the statistical breakdown of energy savings found using the method.

Conclusion

We have proposed that what may be seen as fairly standard techniques in Software Engineering may offer an extra way in to understanding the complexities of Building Energy Efficiency. If we treat the problem of understanding energy and resource flows in the same manner as we would Software Design, the capability for easily handling complexities is built-in from the outset. The software engineering process and diagramming techniques can both systematise the analysis process and make the description of it easier to communicate.

An energy analysis method has been proposed which allows a rapid path through the standard energy analysis techniques, but also factors in energy pathology using rapid time series data. This is presented as a laboratory tested method, albeit with real buildings and data, which may be of considerable benefit to the energy analysis practitioner.

Acknowledgements

The energy flow modelling work described in this paper was part of work funded by the KAP EU Project Knowledge, Awareness and Prediction of Man, Machine, Material and Method in Manufacturing, EU - KAP Large-scale Integrating Project (IP) ICT call 5 FP7-2010-NMP-ICT-FoF [17]. Snape acknowledges the funding from EPSRC grant EP/K033492/1 (Agent based modelling of Electricity Networks).
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Campus and Community Energy Planning Approaches and Examples

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Abstract:
Planning energy use reductions for whole campuses, cities or counties can provide a much more effective way to deal with large scale CO_2 reduction and increased energy efficiency than working one building at a time. Concentrating on large scale, 30 year reduction plans allow strategies to be applied and the costs to be spread across multiple building types and efficiency measures. Strategic energy master plans help gather all members of a community together from the utility providers, the local government, building owners to concerned citizens and create a 30 year road map describing the steps that need to be taken to meet their GHG reduction goals as well as their efficiency reductions and internal rates of return.

This paper will discuss the strategies involved in creating such a plan. Community energy plans require that all energy within the community is accounted for, source and site. There are three main stages to such a plan, uniting the community and arriving at goals that are realistic for their needs. Finding a baseline energy use for the community, this will include buildings energy demand as well as the source energy required to meet this demand. And finally efficiency measures are applied over the lifetime of the plan in order to calculate how much energy the community can save. This paper will focus on how to use energy modelling as an effective tool to calculate large scale energy demand, from generalized modelling to the implementation of efficiency measures. The paper will included examples of projects currently underway in North America.

Introduction
Carbon reduction and security of energy supply are becoming more and more important to cities, campuses and entire counties in North America. Looking to Europe it can be seen that taking on energy reductions on a large scale can significantly help to lower carbon emissions and help countries met their relative energy targets. This paper will look at integrated energy master planning, how it works and how it can be applied to real situations. The paper will highlight the techniques used for generalized modelling for these plans. The paper will then go on to show examples of this type of planning in Guelph ON, and Arlington County VA.

Integrated Energy Master Plans
An effective way to deal with reducing carbon emissions on a large scale is through integrated energy master plans for city, campuses, even counties. These integrate energy efficiency in buildings with efficient supply to reach carbon goals and accepted internal rates of return over a 30 – 40 year period. These integrated energy master plans are road maps which identify the projects and processes that will help the community achieve their goals.

To produce an effective energy master plan it is important to ensure the whole community is involved in the decision making process from the beginning. Figure 1 shows the flow of how an integrated energy master plan would generally proceed.

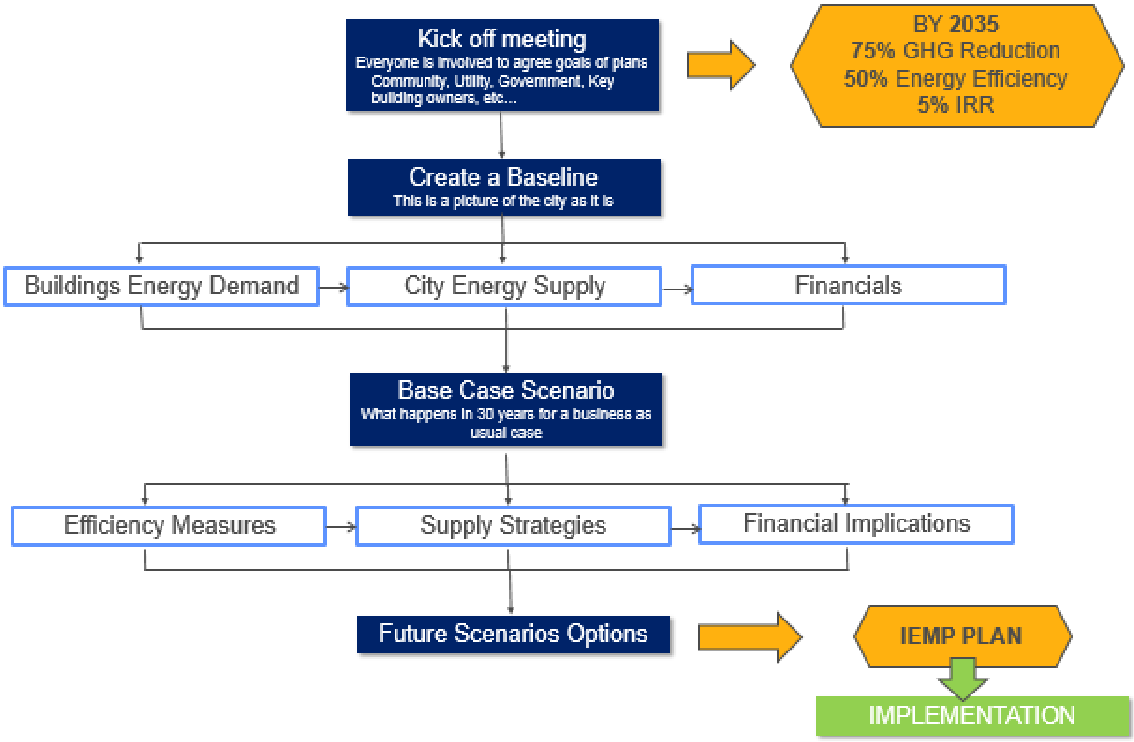


Figure 1 – IEMP flow chart process

The kick off meeting should include all the stakeholders in the process, this would include the city, the utilities, the community, and building owners and managers. In general it is hoped that representatives from these areas become part of the team that writes these master plans. In the kick off meeting energy reduction goals, carbon reduction goals, the period of the plan and the IRR are all decided communally and consensus is reached on proceeding with the plan. It is important in this meeting that the project is communicated clearly so as not to feel overwhelmed by the ambitious targets that are being set. All questions are answered in this meeting, all opinions are taken into consideration and there is no judgment. It is important that at the start of these projects everyone in the room is onboard with the process.

Throughout the process meetings will be held to ensure the community and all involved are happy with the process as well as having any questions or concerns addressed. Once the goals have been established an energy baseline is produced, this gives a picture of the city/campus/county as it stands. The baseline will look at the existing buildings, energy supply and current costs associated with these. From this a base case scenario will be produced. This will look at a business as usual case up to the end of the plan, this will include increasing energy use from future building as well considering possible future costs associated with fuel use. The basecase is then analyzed and efficiency measures are created. Future scenarios are then predicted from this data. These future scenarios are presented to the community and one is chosen to become the integrated masterplan.

Generalized Energy Modelling

One of the key components to the IEMPs is to ensure they are data driven plans. Creating a data driven plan requires energy modelling of the entire city/campus/county. It is impractical and unnecessary to model each building individually and so a generalized modelling technique is used to create data to use to make decisions about energy reduction and efficiency measures. The first task for the building energy modeler is to collect all the data available about the city/campus/county. Utility data as well as city government data can help identify building floor area as well as general energy usage. A walk or drive around the city will also help to identify age and type of buildings. From this key building types are identified, these will generally be: office, residential low, residential high, commercial, industrial and so on, depending on the city. The age of construction then becomes important as well as identifying waves of constructions. These building types will then have sub categories of age applied to them.

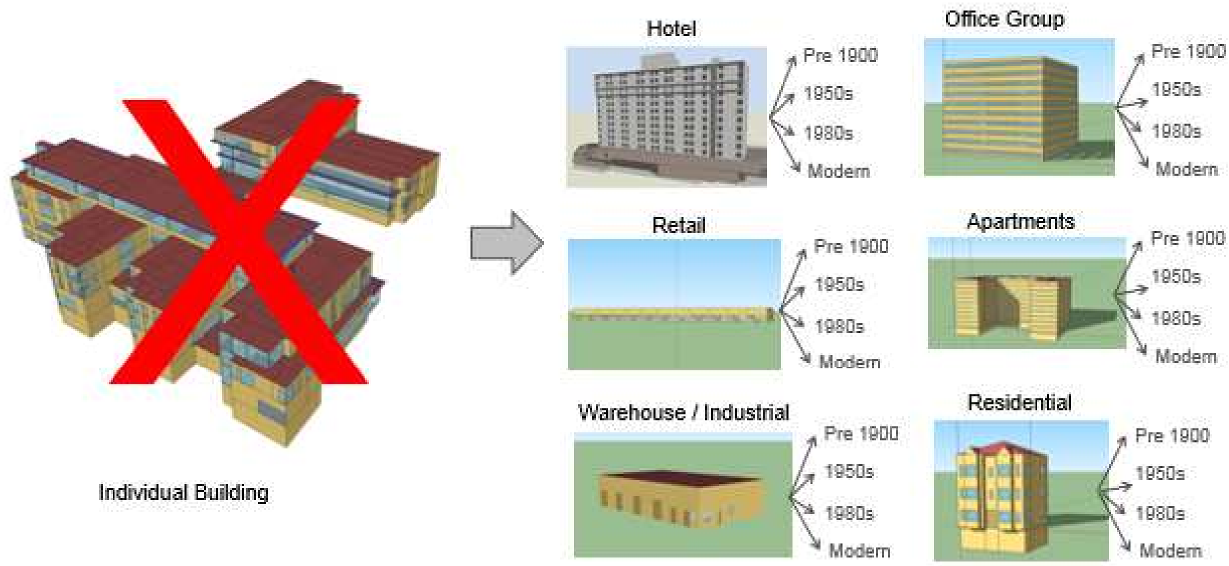


Figure 2 – From individual energy modelling to generalized models

The building code implementation for the city is then analyzed. Along with this constructions and HVAC systems are decided upon for each building type as appropriate to the area. The models are then constructed according to these building codes, constructions and HVAC types. Although these models are generalized building types, they are still complex energy models with all the relevant data that would be required to run an individual building energy model. The models are run on local weather files and the results gathered and energy use applied to the floor areas covered by these buildings. This modelled energy use is then compared to the metered data obtained for the project. The models are then adjusted to take into account large discrepancies. However the models are only adjusted on variables that are hard to predict and are not adjusted just to match to meter. The baseline models are also compared against benchmark data for sanity checks. Once the models are thought to be good enough and they are close to matching to metered data the data is used to assess the supply scenarios for the city. This will then build up the picture of the baseline and basecase scenario of the city.

These models can now be used to analyze where the energy use is greatest in each building type and age. This will lead to where energy efficiency measures can be taken to improve the usage of these buildings. Packages of efficiency measures will then be created. These will be applied to each building type and modelled to predict the energy savings of these measures. Again these will be compared against benchmark data in order to ensure these buildings are going to meet good high efficiency standards. These new energy usages will then be passed on to the supply modelling to feed into a variety of supply scenarios that can be implemented in the city/county/campus.

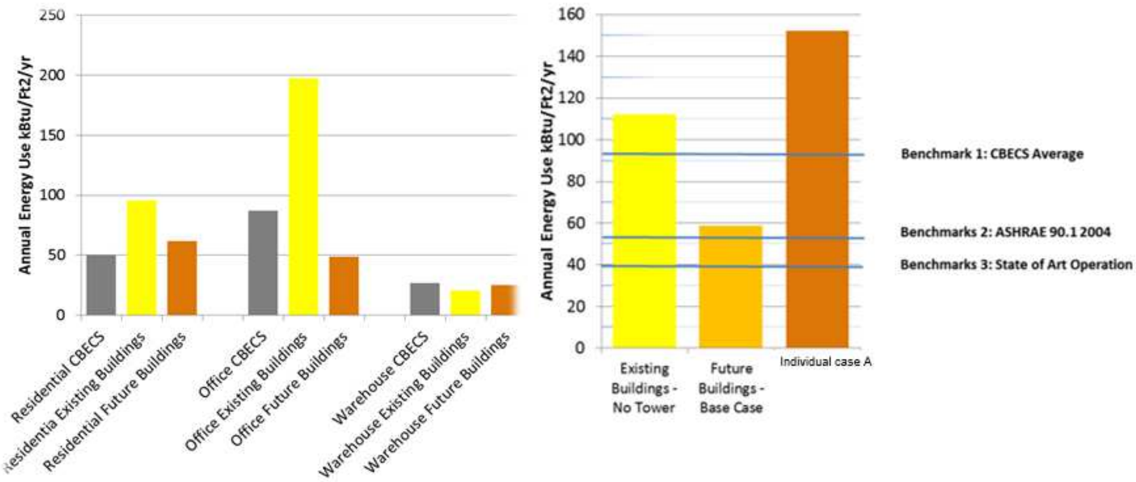


Figure 3 – Comparison of generalized models against CBECS benchmarks

Guelph ON, Canada

Guelph Ontario is a city with approximately 30,000 buildings, a population of 115,000 and a land area of around 86km². The city commissioned an energy master plan in 2004. The baseline carbon for the city was around 12 metric tons of CO_2 per capita, the city set a target to reduce that to 5 metric tons of CO_2 per capita by 2031. The road map was put into place in 2007 and the city has been following its path since then. In 2012 the plan was reviewed and it was decided that it was time to implement the district heating aspect of the plan.

Guelph has over 4000 heating degree days a year with only 180 cooling degree days. Therefore it was recommended in the plan that an efficient district heating system should be put into place in the city. Further analysis of the high density parts of the town was carried out and a district heating plan was set into place. The first part of this plan is being implemented currently with the rest to follow fairly shortly. This is the first district heating system of its type in North America.

A review of the energy efficiency measures for the residential buildings in Guelph is now being carried out in more depth. Again generalized modelling is being used but to a greater granularity in order to create a good business case for home owners to carry out these renovations and ensure a reasonable certainty to the savings predicted. The residential portion of the town is expected to reduce its energy use by 40% over the next 20 years.

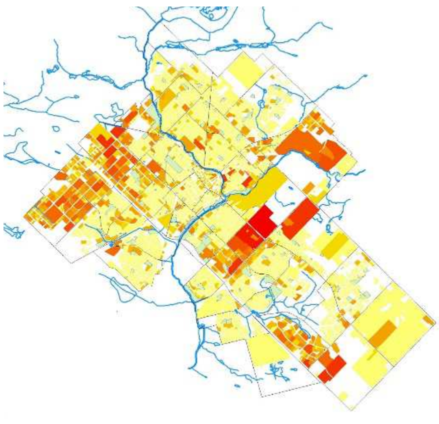


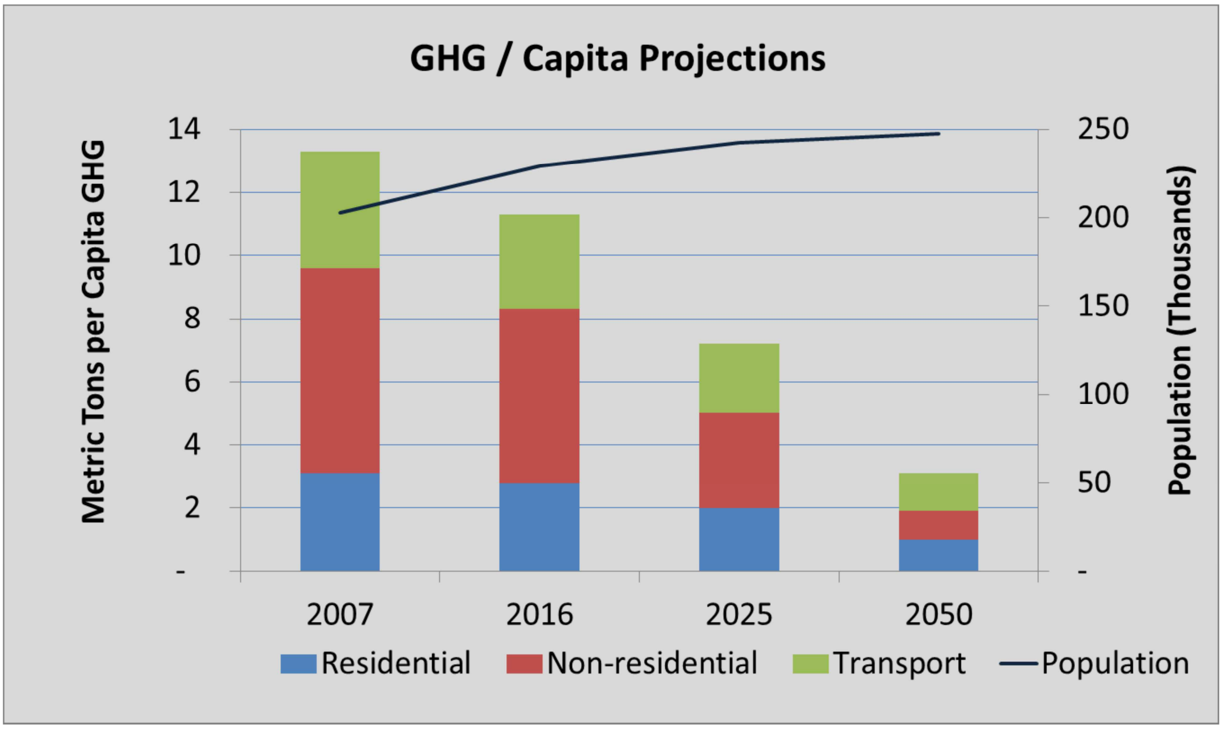
Figure 4 – Thermal map of the city of Guelph to help plan the district heating system in the city

Arlington County VA, USA

Arlington County VA, sits just outside Washington DC. The county commissioned a master plan in 2010 to reduce its carbon from 14.6 metric tons of CO_2 per capita, to a world leading 3 metric tons of CO_2 by 2040. The county has approximately 16,700,000 m² gross floor area and an estimated population of 213,000. The county was modelled using the generalized approach to break down its energy usage by sector and split up its carbon emissions.

The plan required sustained leadership with a non-partisan long term commitment as well as consistent and simple reporting of the goals and progress of the plan. Community engagement was key in setting up and delivering the plan. Any necessary changes in planning policy that were required should be consider and implemented. Building performance certification was included in order to encourage world-class energy efficiency. An integrated utility approach was also required to ensure security and flexibility of supply. As Arlington County is such a big area for a plan, small scale project were broken out to become leaders that the rest of the county could look to and learn from.

Figure 5 shows the projected greenhouse gas reductions over the 40 year planned period split between residential buildings, nonresidential buildings and transport. The increase in population is represented by the line on the graph.



Conclusions

Integrated energy master plans are an effective way to tackle the increasing energy use of cities/campuses and counties. They can package efficiency measures to make them financially more practical and balance energy savings from building to building. Using an integrated approach to energy, looking at the supply as well as the site energy use, helps to lend flexibility to supply as well as security. Generalized modelling helps the planners make decisions based on data rather than conjecture. As in the case of Guelph, this plan was furthered through more detailed modelling to achieve specific goals within the original. The plans are certainly not the end of the story, in fact they are just the beginning for most cities/campuses/counties. They show what is possible and draw out a path to follow to make that happen.

European Energy Codes for Buildings based on EU-mandate480 to CEN, a historic step forward in harmonising EPB procedures

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Abstract

The Recast-EPBD**1** requires an update of the current (2007/2008) set of CEN-EPB standards. This update work started in 2012 and will result in a new set of CEN-EPB standards.. Where possible this work will be done parallel with ISO. This project is based on EU-Mandate 480. This mandate accepted by CEN, requires a really out of the box thinking approach of the standard developers. This project is coordinated by CENTC371 the “Program Committee on EPBD” and is considered to be a step forward in progressing towards European Energy Codes for Buildings. This second generation of EPB standards aims on more comprehensive standards, a clear split between informative text in Technical Reports and normative text in standards, attached excel files to illustrate the calculation procedures etc.. The EPB set of standards and technical reports will support the holistic approach needed for the Nearly Zero Energy Buildings and high performance energy renovation of the existing building stock. The current financial “crisis” made it also clear that we should not rely on instable financial constructions and that it is much more beneficial to invest in reducing and limiting our excessive energy consumption in the build environment. This can be done by investing in energy saving measures and sustainable solutions for existing and new buildings. This new set of EPB standards and supporting tools will help the building professionals and national regulators to make our build environment more sustainable.

Keywords: Energy Performance Buildings Directive; CEN ISO Standards EPBD EPB

1. Introduction

Analyses regarding the use of the in 2007/2008 published set of CEN-EPB 2 standards and the requirements set out in the recast-EPBD showed the clear need for a second EU mandate to CEN in order to improve these standards. The revision will improve the accessibility, transparency, comparability and objectivity of the energy performance assessment in the Member States, as mentioned in the EPBD.
The "first generation" CEN-EPB standards were implemented in many EU Member States "in a practical way". Typically: partly copied in "all in one" national standards or national legal documents, mixed with national procedures, boundary conditions and input data.
For a more direct implementation of the CEN-EPB standards in the national and regional building regulations, it is necessary to reformulate the content of these standards so that they become unambiguous (the actual harmonized procedures), with a clear and explicit overview of the choices, boundary conditions and input data that can or needs to be defined at national or regional level. This implies that the current set of CEN-EPB standards will be improved and expanded on the basis of the recast-EPBD.
The standards should be flexible enough to allow for necessary national and regional differentiation to facilitate Member States implementation. Such national or regional choices remain necessary, due to differences in climate, culture & building tradition and building typologies, policy and/or legal frameworks. This is felicitated by introducing the concept of national Annex and informative EN annex.

2. Work in progress, the on-going work on the EPB standards

Organization of work
Various EPB standards have been developed and are maintained by the following CEN/TC’s:

- TC 089 Thermal performance of buildings and building components;

1 EPBD: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings. Recast-EPBD: DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings; (recast).

2 In this paper EPB stands for “Energy Performance of Buildings” the D for the EU-Directive is intentional deleted in relation to the standards. The EU-directive is of great importance for the EU-member states however these CEN standards could become ISO standards as well and it is more appropriate to use just EPB.

- TC 156 Ventilation for buildings;
- TC 169 Light and lighting systems;
- TC 228 Heating systems for buildings;
- TC 247 Building automation, control and building management;
- TC 371 Project Committee on Energy Performance of Buildings.

These TC's are responsible for the technical content of EPB standards to be revised. CEN/TC 371, the overall responsible coordinating committee, also ensuring that the timetable will be met and that the basic principles and rules, the modular approach and the foreseen improvements of the current set of EPB standards, are in line with the targets indicated and meeting the expectations of the end users.
CEN/TC 371 formulated common Basic Principles on the required quality, accuracy, usability and consistency and a common format for EPB standards, including a systematic, hierarchic and procedural description of options, input/output variables and relations with other standards and elaborated a unique hierarchic system for the EPB standards.
CEN/TC 371[3] prepared the Basic Principles (BP) and the supporting Detailed Technical Rules (DTR), based on the requirements set by the EU Member States and prepared the Over-Arching Standard (the OAS: FprEN15603:2014) on the integrated energy performance of buildings and attached CEN Technical Report to the OAS (FprCEN/TR15615:2014).

3. The Process

- The mandate M/480 explicitly requests for identification and prioritisation of items for revision and gaps in the current set of standards in consultation with the EU member states (MS). For this, EU member states (i.e. the Energy Performance of Buildings Committee as referred to as EDMC in the EPBD) established a so-called Liaison Committee. This CAP-EDMC-LC works also in close contact with the EPBD Concerted Action-III project.
- The expert team working on the program within the CENTC371, the core group of the CEN/TC team-leaders responsible for the EPBD work in these 5 TC's and TC371, here indicated as the CTL, works closely together with this Liaison Committee (LC).
- This close cooperation made it possible for the LC to verify and monitor progress with respect to the requirements set by the Member States and eases the work of CEN/TC 371 by serving as an intermediary for questions from CEN/TC 371 to the EU member states experts.

Based on this working structure CEN/TC 371 prepared the general frame for the package of standards to support EPBD directive. This includes both the standardised calculation structure and the guidance for the drafting the individual EN EPB standards as it is currently on-going.
Considering the requirements from the mandate M/480 the following, general conclusions regarding the setup of EPB standards have been drawn:

1. The complexity of the building energy performance calculation requires a good documentation and justification of the procedures. Informative text is required but it will be separated from actual normative procedures to avoid confusion and unpractical heavy documents. Therefore, each EN EPB standard shall be accompanied by a Technical Report where all related informative material will be concentrated.[4]
2. The complexity of the building energy performance calculation requires also a very good coordination and testing of each calculation module. Therefore, each EN EPB standard shall be accompanied by a spread-sheet where the proposed calculation algorithms and data input/output are tested and proved to be consistent. A Software Tool to accommodate the Over-Arching Standard and check the calculation modules of the total set of EPB standards has been developed. With this excel based software we will be able assure that the in/output files of the various connected EPB standards are valid.

The relation of the above mentioned set of draft documents and the process setup is illustrated in figure 1

3CEN/TS 16628:2014 Energy Performance of Buildings - Basic Principles for the set of EPBD standards
CEN/TS 16629:2014 Energy Performance of Buildings - Detailed Technical Rules for the set of EPB-standards
FprEN 15603:2014 Energy performance of buildings - Overarching standard EPBD
FprCEN/TR 15615:2014 Energy Performance of buildings — Module M1-x — Accompanying
Technical Report on draft Overarching standard EPBD (FprEN 15603)
4 Either as a separate TR or if very limited as an informative annex to the standard. It is also possible that a TR will cover more standards.

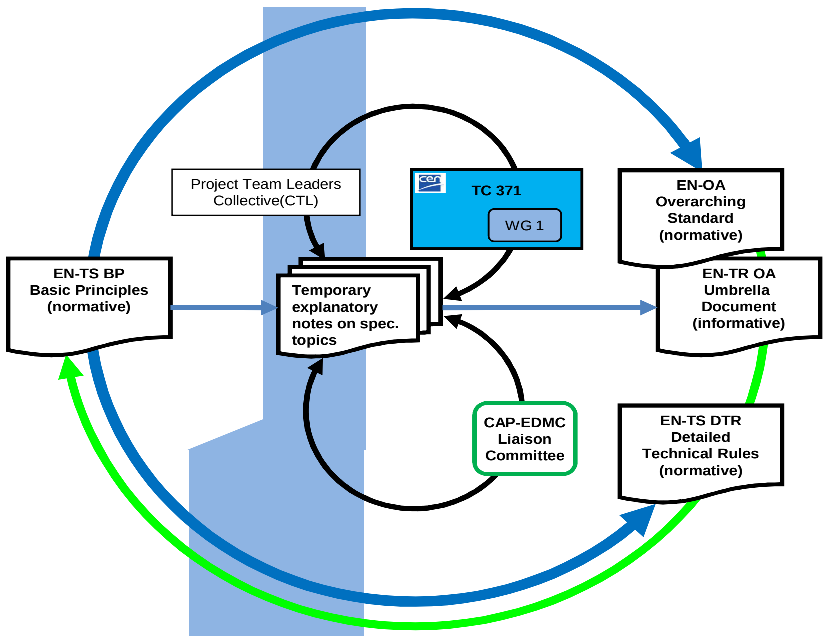


Fig. 1 – Iterative development process around the coordinating CENTC371 and inter-relation between the documents as has been developed.

4. The deliverables of CENTC371

4.1 CEN/TS Basic Principles

CEN/TS 16628:2014 Energy Performance of Buildings - Basic Principles for the set of EPBD standards. This TS provides a record of the rationale, background information and all choices made in designing the EPB package. These basic principles are based on the analysis of the weak points within the current EPB package and on an evaluation of requirements by the EU Member States and the outcome of the IEE-project CENSE (see http://www.buildup.eu and http://www.iee-cense.eu/).
This CEN/TS 16628 Basic Principles provides guidance on the required quality, accuracy, usability and consistency of each standard and the rationalisation of different options given in the standards, providing a balance between the accuracy and level of detail, on one hand, and the simplicity and availability of input data, on the other.

4.2 CEN/TS Detailed Technical Rules (CEN/TS DTR)

CEN/TS 16629:2014 Energy Performance of Buildings - Detailed Technical Rules for the set of EPB-standards. This TS is based on the CEN/TS 16628 and provides mandatory detailed technical rules to be followed in the preparation of each individual EPB standard. This is in addition to the CEN drafting rules and complementary to the prEN15603 (EN OAS, containing the common terms, definitions and symbols and the overall modular structure for the EPB standards), the TS DTR specifies rules on:
-a common format for each standard, including a systematic and hierarchic structure to pinpoint the position of the standard within the framework of CEN EPB standards and procedural description of options, input/output variables including:
-a clear separation of the procedures, options and default data to be provided as default CEN option in an annex B but also allowing for national or regional choices conform the normative annex A of each of the EPB standard (where appropriate);
-a specification of the input data, also indicating the source of the data if this is the output calculated according to another EPB standard or related product standard;
-a specification of the intended output that is intended to provide the energy performance assessment results, the related data necessary for their proper interpretation and use, and all relevant information documenting the relevant boundary conditions and calculation or measurement steps.
-an informative CEN Technical Report, accompanying each standard5, according to a common structure, comprising at least the results of internal validation tests (such as spread sheet calculations for testing and demonstrating the procedures), examples and background information. If possible all informative parts which are currently part of the current EPB standards will be moved to these technical reports.

5 This to significantly reduce the length of the standards and strengthen their focus, thus facilitating the adoption (including translation) in national/regional regulations.

4.3 Energy performance of buildings-Overarching standard EPB: FprEN 15603: 2014

The Overarching Standard (FprEN 15603, OAS) specifies a general framework for the assessment of the overall energy use of a building, and the calculation of energy ratings in terms of primary energy using data from other EPB standards providing methods for calculating the energy use of services within a building (heating, cooling, humidification, dehumidification, domestic hot water, ventilation, and lighting). This assessment is not limited to the building alone, but takes into account the wider environmental impact of the energy supply chain. The FprEN OAS replaces EN 15603:2008 and parts of other EN and/or EN-ISO standards published in 2007-2008 under the EU-mandate M/343. These items are now covered in this FprEN-OAS.

The FprEN OAS handles the framework of the overall energy performance of a building, covering inter alia:

1. common terms, definitions and symbols;
2. building and system boundaries;
3. building partitioning;
4. unambiguous set of overall equations on energy used, delivered, produced and/or exported at the building site, near-by and distant;
5. unambiguous set of overall equations and input-output relations, linking the various elements relevant for the assessment of the overall energy performance of buildings which are treated in separate standards;
6. general requirements to standards dealing with partial calculation periods;
7. general rules in setting out alternative calculation routes according to the calculation scope and requirements;
8. rules for the combination of different partitioning.

The FprEN OAS provides a systematic, clear and comprehensive, continuous and modular overall structure on the integrated energy performance of buildings, unlocking all standards related to the energy performance of buildings.

The overall framework provided by the FprEN OAS will enable a step-by-step implementation by the EU Member States, taking also into account the nature of each procedure identifying the typical type of user. In order to progress on harmonization, reproducibility and transparency, the FprEN OAS provides default CEN options (choices for options and default values). At relevant positions in the standard a reference is made to the Annex B where these default values and options are given. At a national level these default CEN values and options may be replaced by national choices to be published in a National Annex to this standard, following the normative structure provided in Annex A. This is to provide flexibility to the EU member states in the application of the set of CEN standards.

More information is given in a Technical Report accompanying the overarching standard. The justification for the CEN defaults and options are provided in the TR. This procedure as followed for the FprEN15603 and will be followed for all EPB standards where default CEN options have to be considered.

All EPB standards will include a normative Annex A including the normative model for tables to be filled by the National Standard Body if they choose to publish a national annex overriding the values and choices in the informative Annex B where all CEN options and defaults are given.

Current (May 2014) status: this FprEN has passed the enquiry procedure, all comments including late feedback from MS's have been processed. CENTC371 accepted this draft standard for sending out for Formal Vote. This means that all National Standard Bodies are asked to vote if this standard acceptable as CEN standard. This voting is expected around September 2014. Only limited editorial changes can be accepted, after a positive outcome of this voting the OAS will be published January 2015. The current CENTC371 document N342 is this FV version can be considered as almost equal to the final version to be published in 2015.

4.4 FprCEN/TR 15615:2014 Energy Performance of buildings — Module M1-x — Accompanying Technical Report on draft Overarching standard EPBD (FprEN 15603:2014)

This CEN-TR refers to the overarching EPB-standard, FprEN 15603:2014.

It contains information to support the correct understanding, use and national implementation of this standard. This TR includes:

-explanation on the procedures and background information and justification of the choices that have been made;

-reporting on validation of calculation procedures given in the standard;

-explanation for the user and for national standards writers involved with implementation of the set of EPB standards, including detailed examples.

The version of the FprCEN/TR OAS:2013 send out for enquiry last year is special in the sense that it also contains proposals for specific revisions of the procedures given in prEN 15603:2013. This was the result of the production following order. The draft OAS was first released for enquiry after which the TR had to be finished which resulted in progressing insight. When commenting during Public Enquiry the prEN 15603, the commenters have been requested to take these updated proposals into account.

Current (May 2014) status: this TR has formally been approved under the CEN Technical Approval procedure. CENTC371 decided to launch a second TCA to be able to synchronise this TR with the current AOS.

5. Hierarchic numbering system - Modular structure

Overarching		Building (as such)		Technical Building Systems										
	Descriptions		Descriptions		Descriptions	Heating	Cooling	Ventilation	Humidification	Dehumidification	Domestic Hot water	Lighting	Building automation & control	PV, wind, ..
sub	M1	sub	M2	sub		M3	M4	M5	M6	M7	M8	M9	M 10	M 11
1	General	1	General	1	General									
2	Common terms and definitions; symbols, units and subscripts	2	Building Energy Needs	2	Needs									
3	Applications	3	(Free) Indoor Conditions without Systems	3	Maximum Load and Power									
4	Ways to Express Energy Performance	4	Ways to Express Energy Performance	4	Ways to Express Energy Performance									
5	Building Functions and Building Boundaries	5	Heat Transfer by Transmission	5	Emission & control									
6	Building Occupancy and Operating Conditions	6	Heat Transfer by Infiltration and Ventilation	6	Distribution & control									
7	Aggregation of Energy Services and Energy Carriers	7	Internal Heat Gains	7	Storage & control									
8	Building Partitioning	8	Solar Heat Gains	8	Generation & control									
9	Calculated Energy Performance	9	Building Dynamics (thermal mass)	9	Load dispatching and operating conditions									
10	Measured Energy Performance	10	Measured Energy Performance	10	Measured Energy Performance									
11	Inspection	11	Inspection	11	Inspection									
12	Ways to Express Indoor Comfort			12	BMS									

13	External Environment Conditions													
14	Economic Calculation													

Fig. 2 – The modular structure of EPB standards

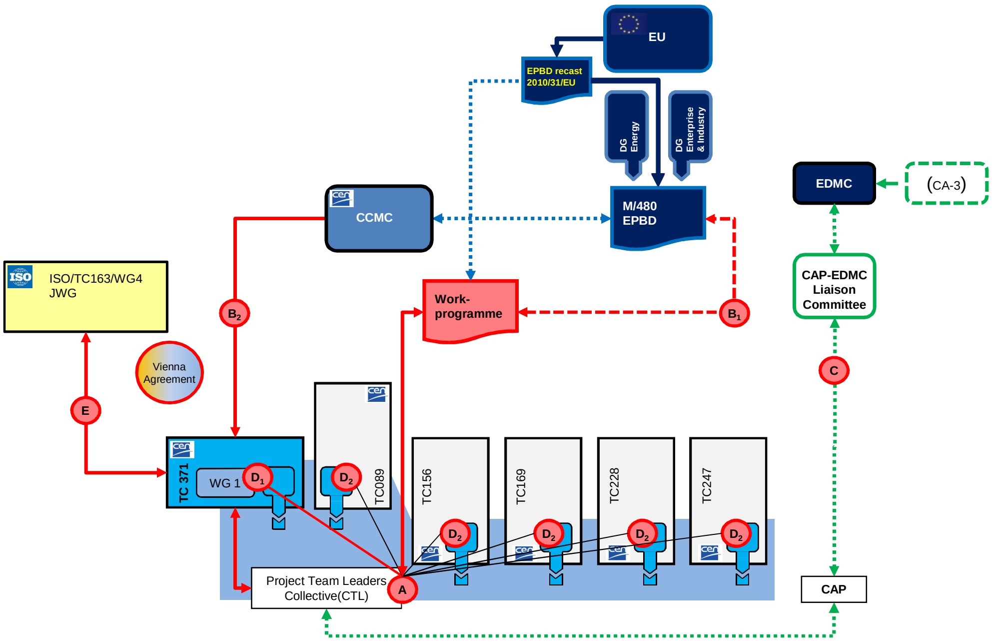
Mandate M/480 asks for the setup of a coherent and hierarchically numbered system of EPB standards. The setup of such a system would have been rather simple when the whole system should have been drafted from scratch. However, with the major part of relevant issues already addressed in the existing set of EPB standards (and given the revisions required), renumbering the existing standards is not feasible.
In order to work around this problem, a modular structure was developed, allowing for addressing documents given hierarchic positioning in that structure. By adding the identification code of a specific cell of the modular structure (see Figure 2) the purpose of a standard (and/or specific clauses of the standard) can be identified easily.

6. Calculation tool and Module description

The complexity of the building energy performance calculation requires also a very good coordination and testing of each calculation module to ensure coherence and the software-proof of the set of EPB standards. Therefore, each EN EPB standard shall be accompanied by an excel-sheet in which the proposed calculation algorithms and input/output data are presented, tested and proved coherent.
For the revision or development of new EPB standards under the M/480 project and in addition to the CEN TS 16629 (DTR) a default calculation spread sheet is provided.
The spread sheet (MS Excel©) includes a complete calculation of an EPB standard. The template in the DTR is based on an example to illustrate the way of working. It demonstrates how the standard writers shall test and prove that the developed standards are software proof. Clear guidelines are given to structure each module spreadsheet.

7. Co-operation with ISO

Several (11 of the 42) first generation of EBP standards are EN-ISO standards. They have been developed under the Vienna Agreement. Revision of these standards requires co-operation with the ISO/TC responsible. The central co-ordination of the preparation of a set of international standards on the energy performance of buildings at the ISO level is in the hands of ISO /TC 163/WG 4, Joint Working Group of ISO TC 163 and TC 205 on energy performance of buildings using a holistic approach.
The main leading and active experts in CEN (members of the CTL of CENTC371) are among the main leading and active members of this ISO Joint Working Group.
In order to co-ordinate revisions of EN-ISO standards required under mandate M/480 and the activities within the responsible ISO/TCs, CEN/TC 371 established a liaison with ISO/TC163/WG4 (see Figure 3). Relevant documents and information on proposed work items is exchanged between CEN/TC 371 and ISO/TC 163/WG4 on a regular basis to prevent obstacles in the progress of the mandated work.
Considering the coherent set of EPB standards to be developed under mandate M/480, co-operation is established with the relevant ISO/TCs (ISOTC163 and ISOTC205), with as preferred outcome the publication of combined EN-ISO standards. This co-operation with ISO aims to avoid serious duplication of work, to avoid incompatibilities in (input) product data, procedures and (output) energy performance data.
It our intention to use in the future an ISO series of numbers to make it more easy to refer to these standards and recognize them as belonging to the package of EPB standards (future ISO numbers:52000-till-52150).



A Central co-ordination, including monitoring of the basic principles and rules and preparation of the OAS
B Procedure and process management as set by requirements of the mandate M/480
C Consultation: setting and overarching requirements from EU member states.
D Preparation / Revision of the specific standards by Core Project Teams per TC with continuous central co-ordination from the CAP (CTL) of TC371.
E Tuning revisions of EN-ISO EPB standards with ISO.

Fig.3 - Schematic operational structures.

8. How the EPBD interacts with the ECODESIGN Directive

Saving energy in the build environment requires not only that products consuming electricity and fuels are designed to be intrinsically more energy efficient. The interaction of a product with the rest of the system or installation in a building plays an important role. This appears obvious for a number of product categories such as building equipment for ventilation, heating, cooling, lighting and control and automation. With the increasing application of electronic and communication technologies, this is also increasingly true for many other products, used in buildings but not considered as EPB related, that become 'smart' and 'networked', and can be controlled through wider systems. When policies such as the Ecodesign Directive use a narrow product-based view, products are considered irrespective if their surroundings and tested in standard conditions. If only their technical efficiency is considered, this approach may look straightforward but misses the savings that can be expected from ensuring that the product is also correctly sized, fitted and controlled to render its service optimally in a well-designed building installation. While it may not be difficult to reach an EU regulation of systems under product policies, it may be possible to find creative ways for tackling at least a part of the energy savings.
On one hand we have the Ecodesign Directive requiring through EU regulation minimal energy performances of energy using products. On the other side we have the EPBD where the EU Member States are obliged to require minimal target values for the energy performance of buildings, also having specific requirements for the overall thermal performance and the energy performances of the heating, ventilation, lighting and cooling systems. The debate is still ongoing about whether systems (or part thereof) should be regulated under product policies such as Ecodesign. It seems an easy approach which may lead to sub-optimal solutions. What are the potentials and conditions for successfully grasping energy efficiency in systems? Should additional pieces of legislation be considered to target higher energy savings? The EPBD requires the MS's to put national regulation in place to regulate the minimum system efficiencies at national level.
As these above questions are still under consideration CEN will try under the current Mandate 480 EPB-project to coordinate the work with work under the Mandate 495 on Ecodesign.
The CEN expert teams working on the different EPB-system standards have to check if the product data available on basis of product standards and/or related EU regulations are sufficient as input for their system standards. The CEN product Technical Committees and/or experts preparing the EU regulatory text have to be convinced that using the EPB system approach, to describe and test the products, is the

most efficient way to ensure effective energy performance targets for products, systems and finally the buildings.
A lot of products on the market used in building systems are not just single performing products. They often include controls, auxiliary elements like pumps, ventilators, frost-protection, etc.. They can be considered as subsystems which makes the Eco-design product declaration less transparent.

9. Conclusions

The revision of the current set of CEN and ISO EPB standards is in progress. To make the set of EPB standards work as a horizontally well coordinated set of standards the CEN Technical Specifications CEN TS 16628 and 16629 the Overarching Standard EN15603:2014 and the CEN Technical Report prCEN TR 15615 have been developed. These standard documents are expected to give a sound basis for the development of the total set of EPB standards to be ready by 2016. It is expected that during this process the EN15603 and TR15615 will be updated as well.

Session

Technologies

Case study on Trigeneration technology: An approach towards higher energy efficiency and urban emission reduction strategies; quantification of energy efficiency, emission reduction potential and policy implications

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Abstract

The energy demand in India is growing at a very fast rate, the present energy generation could not be able to keep pace with this increasing demand with energy shortage of 6.2 % and peak shortage of 2.3 % (ref 1). To address the increasing gap between demand and supply there is an urgent need to bridge the gap through energy efficiency and integration of renewable energy in the energy mix of the country. This paper presents a new concept in Indian building sector which addresses the energy efficiency through Trigeneration technology. A gas engine with natural gas is used to produce power and the waste heat from the engine to produce power and the waste heat for producing cooling and heating through Vapour Absorption Machine (VAM) and hot water recovery from Low Temperature (LT) jacket water. This increases the efficiency upto 85 % or even more as compared to the conventional methods of power production. The present paper discusses one such case study on a pilot project implemented under the Indo German Energy Program. Indo German Trigen project is the first project successfully implemented under the International Climate Initiative in India. The pilot project is funded by the German Federal Ministry of Environment, Nature Conservation Building and Nuclear Safety (BMUB). This paper presents the information on the techno-economics of the pilot project at New Delhi.

Introduction

India is the world’s fourth largest consumer of energy. According to an estimate the energy demand could increase by at least four times by 2032 compared to present level. Electricity production is mainly based on the burning of fossil fuels, since they are widely available and easy to utilize. Table 1 (ref. 2) shows the present energy mix in Indian power sector. More than 25 % of energy and 70 % of gas is imported. The energy demand in India is growing at a very fast rate, the present energy generation could not be able to keep pace with this increasing demand with energy shortage of 6.2 % and peak shortage of 2.3 % (ref 1). Hence there is a need to keep import dependency in the conventional energy sector as low as possible; strategies for enhancing energy efficiency and utilizing renewable energy are increasingly becoming the focus of India’s energy policy.

Due to the gap between demand and supply frequent power failure occurs; the energy supply

is then met through alternative energy sources like diesel generators and battery stored power (invertors). This contributes to already energy starved and polluted city by the presence of industries and transportation sector in the vicinity of the national capital that use conventional fuel to meet energy demands. The downsides of this practice have become more and more obvious, among them GHG emission, ODP substances, power reliability, quality and shortages, etc. are a major concern. The diesel generator sets contribute to the pollution in cities facing frequent power cuts due to unplanned development and geographical locations, etc. The diesel generators in this case can be replaced by an energy efficient Trigen technology in applications which has simultaneous use of power, heating and cooling requirement.

Table 1: Installed capacity of power generation in India

S No	Fuel	MW	Share (%)
1	Total Thermal	153848	68.14
a	Coal	132,288	58.59
b	Gas	20,360	9.02
c	Oil	1,200	0.53
2	Hydro Energy	39,624	17.55
3	Nuclear Energy	4,780	2.12
4	Renewable Energy	27,542	12.20
	Total	2,25,794	100

The Trigeneration demonstration plant (figure 1) utilizes natural gas as fuel to produce power and the waste heat recovered from the exhaust gases from the gas engine for cooling through absorption chillers in summer, and low temperature (LT) heat for heating purpose or electricity and heating in winter. Trigen technology is by and large unknown in India and is not sufficiently tested. In the most common type of Trigen system, fuel is used by a prime mover to drive a generator to produce electricity. The waste heat from the prime mover is recovered to provide useful thermal energy for cooling and heating. This arrangement is called topping cycle. Two most common toping cycle Trigen configuration are as given below:

I. Type I: An engine/turbine burns fuel to generate electricity and the heat recovered from the exhaust gases and jacket water is utilized for heating and/or cooling.
II. Type II: A steam/gas turbine uses high-pressure steam to drive a generator to produce electricity. Low pressure steam extracted is used for heating and/or cooling.

Whereas in bottoming cycle the fuel is used to produce thermal energy in an industrial process and

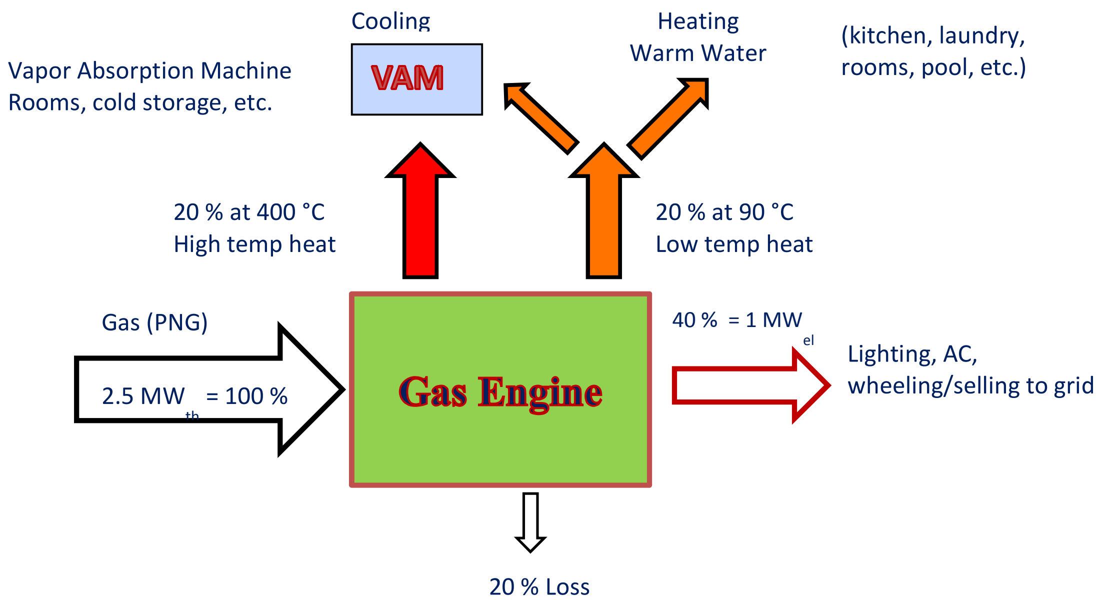

Figure 1: Schematic of typical Trigeneration system installed at demonstration site

heat from the process otherwise wasted is used to generate power.

Case Study: Trigeneration in an operational hospital at New Delhi

There exists a huge energy saving potential in India among various sectors identified for replication of Trigen on the basis of developed criteria suited to Indian building sector. The basic parameters used for selection of a building suitable for Trigen are as follows:

1. 24 hours operational building
2. Simultaneous requirement of electricity, heating and cooling
3. Backup arrangements
4. Power supply, failure, fluctuations, etc.
5. Space availability for installing the system
6. Centralized heating and cooling system
7. Availability of natural gas as fuel
8. Check for regulatory requirements

For identifying a suitable building which match the above criteria feasibility studies at around 10 buildings were conducted among which a government hospital Jai Prakash Narayan Apex Trauma Center (JPNATC), All India Institute of Medical Sciences (AIIMS) was selected finally based on the feasibility study conducted. A picture and location of pilot plant of the building is shown in figure 2. Followed by the feasibility study the building was further analysed for implementation of Trigen system.

The Trigen system installed at JPNATC has three key components viz. gas engine, electrical chiller and Vapour Absorption Machine (VAM) which uses a non-Ozone Depleting Potential (ODP) substance and has no Green House Gas (GHG) emissions.

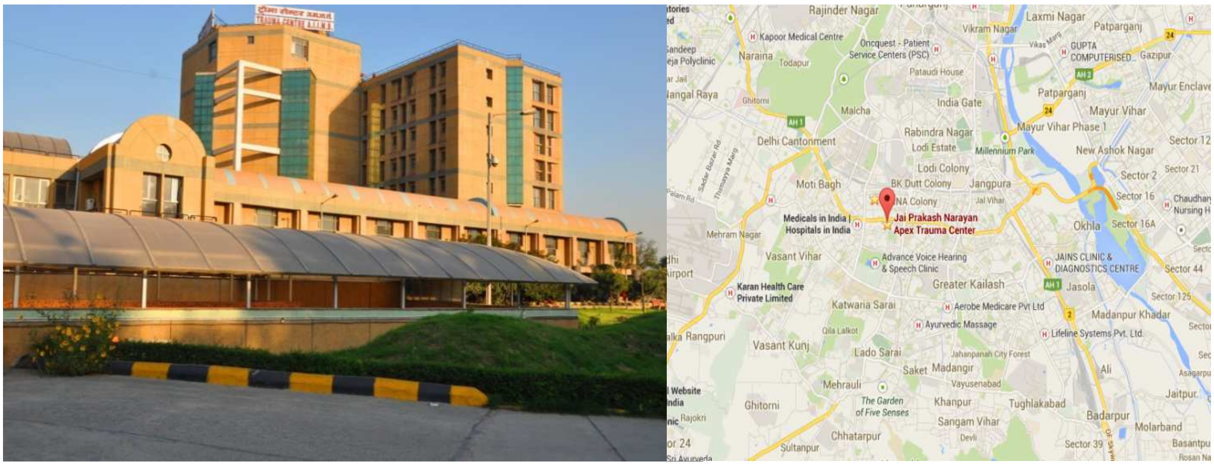

Figure 2. Pilot project demonstration site

The major components of the pilot project were gas engine, VAM and electrical chiller controlled through variable frequency drive for additional cooling requirements. The sizes of major equipments installed at JPNATC are given in Table 2 below.

Table 2: Installed components of Trigeneration plant installed at JPNATC

Equipment	Make	Size	Parameter
Gas Engine	Schmitt Enertec	347 kW	37 % elec. eff.
VAM	Thermax	105 TR	COP 0.7
Chiller	York	250 TR	COP 4
Cooling Tower	Mihir	400 TR (340 m3/hr)	1800 kCal/hr

The demonstration site has a total energy consumption of 1.2 MW of electricity and cooling capacity of 800 TR through screw chillers and hot water requirement for kitched, laundry and sterilization through diesel fired boilers. The hospital has two separate grid lines as emergency power supply backup during main grid failures and also has installed capacity of 3 MW through three diesel generator of 1 MW each to meet power demand during emergencies

In the demonstration plant a gas engine (natural gas as fuel) is installed to produce power up to 347 kW and the exhaust gas from the gas engine released at a temperature of 420 °C was supplied to VAM. The single effect VAM installed at site utilizes the heat from the exhaust gas and High Temperature HT water from the engine and produces chilled water at 7 °C through absorption-refrigeration. The VAM utilizes LiBr and water as absorbent and refrigerant and the chilled water thus produced is circulated throughout the existing child water pipelines in the building. The low temperature (LT) water from the jacket of the engine is used to pre-heat water in boiler supplied for kitchen/laundry application.

Table 3: Estimation of baseline energy consumption at JPNATC (year 2010)

Energy Type	Cost per annum		Electricity / fuel consumption
	Million Rs	**€ (x 1000)**	kWh / liters
Power	26.5	311.8	3 million kWh
Cooling	14.6	171.8	1.6 million kWh
Heating	1.5	17.6	43800 lit/annum
Project baseline	426	501.2	--

With the gas prices at Rs 19/scm and electricity prices at 9.10 Rs/kWh with diesel prices (15 Rs/kWh) at 50 Rs/liter the baseline revealed that the estimated payback period of the project was 3.2 years. However, during the last three years the natural gas prices has gone up drastically with marginal increase in diesel prices. Due to few power failures and dual supply from grid the operation of diesel generator was very minimal and hence the economic viability has reduced under the present energy scenario. In addition to this the rate at which the electricity is supplied to the hospital has also reduced, this was due to switching form a temporary grid connection to a permanent grid connection after the implementation of the project. The Table 3 presents the baseline energy consumption at the hospital (estimate year 2010). The Table 4 presents the various costs taken into consideration in estimating the baseline of the hospital assessed in the year 2010.

Table 4: Savings from trigen plant estimated during the year 2012

Parameters	Value		Energy costs/ savings
	Million Rs	Million €	
Equipment cost	35	0.6	Power (347 kW) – Rs 15.1 million
Additional project cost	6.2	0.103	Cooling (VAM 105 TR) Rs 9.8 million
Total project investment	41.2	0.69	Heating (20 kW) Rs 1.3 million
Annual savings from Trigen	13.0	0.22	
Project payback	3.2 Years		

The overall efficiency of the plant increased from 36 % (comparison of diesel generator or grid) to 67 % after installation of the Trigen plant. As the hospital is using only 20 kW of hot water from LT circuit, the efficiency can further be increased by increased utilization of LT hot water.

The plant covers about one-third of the energy demand of the hospital and has resulted in energy saving up to 660,000 kWh per annum with GHG emission reduction of 1700 tCO_2 per annum due to the utilization of waste heat in VAM, energy efficient centrifugal chiller and diesel savings in the boiler. The plant was commissioned in October 2012, since then the gas prices has risen from 19 Rs/scm to 45 Rs./scm and has also impacted the project payback from 3.2 years to more than 5 years.

After the commissioning of the plant it is being monitored for the performance and the data gathered will be made online on www.trigenindia.com from May 2014 onwards.

Market potential of Trigen technology

To identify the potential and attractive sectors for replication of Trigen a market study was conducted. According tot the study the potential of Trigeneration is more than 10000 MW in the Indian building sector (ref. 3). The building sector can be divided into the following categories according to building byelaws as shown in figure 4.

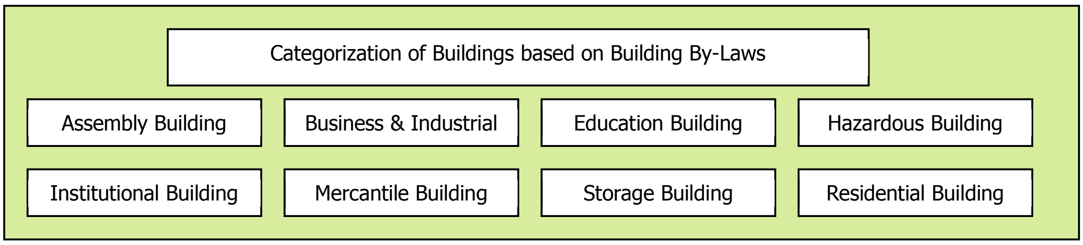

Figure 4: Categorization of building types based on building by-laws

A detailed study was conducted in select industrial sectors on the basis of market attractiveness and financial attractiveness. The Internal Rate of Return (IRR) was calculated on the basis of the following parameters:

1. Electricity tariff of €. 0.089 per kWh
2. Tariff for sale of surplus power to grid € 0.074 per kWh
3. Average heat to power ratio of the building category
4. Capacity utilization was considered constant for all building category
5. Price of gas at € 0.18 per m3
6. Operating hours of cogen/trigen plant per annum as 8000 hrs
7. Weather conditions of Delhi (composite climate) for all building types

Operating hours of each building type used in estimation were considered as given below:

1. Private/Government office: 2340 hrs/annum
2. Retail: 5040 hrs/annum
3. Hotel: 8760 hrs/annum
4. Hospital: 8760 hrs/annum
5. Airport: 8760 hrs/annum

The values for project IRR & operating hours per annum for each of the building were normalized to a score of a maximum of 10 and rated accordingly. The score for financial attractiveness was given a weightage of 60 % & the annual operating hours was given a weightage of 40 %, to arrive at the final score for the market attractiveness. The figure 5 shows the sector wise ranking on the basis of the above criteria. According to the study hotel industry is the most attractive market followed by airport, hospitals, etc. the size of the bubble denotes the replication potential in the sector. A sector wise potential is shown in Table 5.

Figure 3 An inside view of the Trigeneration demonstration pilot plant at JPNATC

A map with identified with Trigenreration potential was prepared and is now available for feedback and further improvement and refinement. The map can be downloaded from the project website (ref. 5).

Table 5 Potential of Trigen in select industrial sectors

Industry	Potential MW
Alumina	59
Caustic Soda	394
Cement	78
Cotton Textile	506
Iron & Steel	362
Man-made fiber	144
Paper	594
Refineries	232
Sugar	5,131
Sulphuric acid	74
Total	7,574

Enabling favourable policies for Trigeneration plants

Since there are no regulations defined for transportation of chilled water to nearby users there is an urgent need to provide support for such installations through favourable policies. Policies favouring energy efficient Trigenreration is required in the Indian building sector with incentivising such installations. Fuel allocation to plants with higher overall efficiency when compared to the large gas based power plants must be given priority; trigeneration not only have higher efficiency but also have no or very less emissions and transmission and distribution losses. This also curbs issues like theft and user can control the power factor reduce GHG emissions. To provide a level playing field to gas based Trigen project a policy support is recommended. There exists a Cogeneration Act (ref 4) in Germany in order to promote Trigeneration, there exists a similar law in Indian energy sector to prioritize energy efficiency.

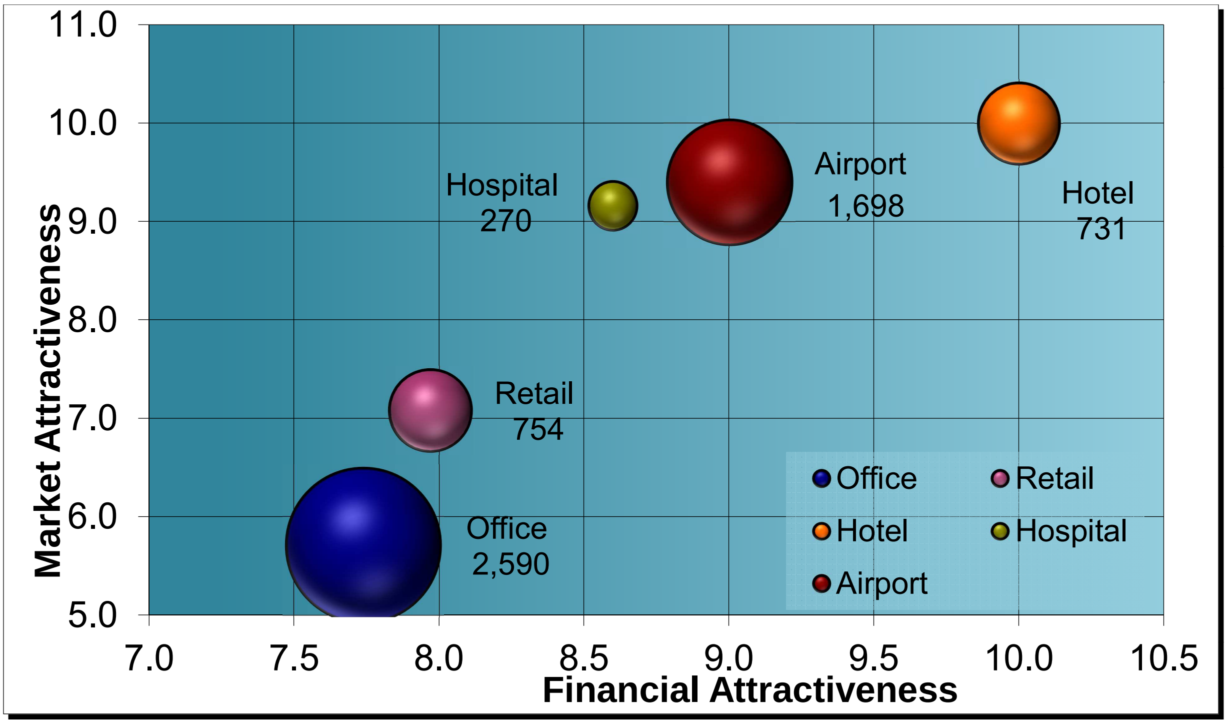

Figure 5: market attractiveness of various sectors identified for replication

Conclusion

Natural gas based Trigen technology has many fold advantages as compared to the conventional way of power generation. The efficiency of gas based Trigen plant achieved is 67 % and it can be as high as 85 %, even more as compared to 25 % of energy received from centralized power plants. Apart from efficiency benefits the advantages are even higher viz. higher reliability, low carbon footprint, environmental benefits, GHG reduction, fuel flexibility, diesel abatement, to name a few.

The pilot project demonstrates the success achieved in implementing a plant in an operational building showcasing the possibilities of integration in the existing and operating plant. However, there is an urgent need to frame policies in order to promote the concept to a larger user.

Acknowledgement

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Is EER Enough? Investigation of Energy Saving Potential for a Room Type Air Conditioner - a case of an office building in Istanbul

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M.Sc., M.Sc., M.Sc., Ph.D., Prof. Dr.

Abstract

The world primary energy use almost doubled between 1973 and 2010. This leads for problems in energy supply security, over-usage of energy resources and related environmental impacts such as climate change. One of the key sectors in terms of energy consumption can be stated as the building sector. The share of energy consumption of the building sector is in between 20% and 45% in developed countries. Main reasons for these figures can be due to growth in population, greater demand for building services, the need for better comfort levels, and longer duration of occupants spent time inside buildings. Currently, because of climate change impact and comfort conditions concerns, heating, ventilation and air conditioning (HVAC) systems have started to be widely used in building sector especially in commercial ones. In this framework, determination of energy saving potentials for air conditioners (ACs) has an utmost importance for climates with moderately hot weather such as Turkey. For this purpose mainly EER (Energy Efficiency Ratio) and newly developed SPF (Seasonal Performance Factor) are utilized. In this paper, by means of a field test conducted in an office building in Istanbul, the results of energy saving ratio of variable speed AC over non-variable speed AC with the same EER values are compared in order to show the need for a new indicator, like SPF.

Introduction

Currently, due to climate change impact and comfort conditions concerns, heating-ventilation-air conditioning (HVAC) systems have started to be widely used in the building sectors. European Energy Performance of Buildings Directive [1] has proposed utilization of high energy efficient HVAC systems. Especially, in buildings equipped with room type air conditioners (ACs), efficient technologies should be taken into consideration, since the usage of individual systems are more consumer oriented, i.e. primary criteria is the comfort rather than efficiency.

Generally, Energy Efficiency Ratio (EER) and Coefficient of Performance (COP) are the evaluation methods for ACs cooling and heating performances, respectively. EER shows cooling capacity (W) per 1 W of power consumption at rated capacity whereas COP shows heating capacity (W) per 1 W of power consumption at rated capacity [2].

In order to optimize the capacity of ACs, variable speed control can be accepted as one of the applicable measures since 1980. Previously, the constant speed ACs have been widely used in the market while now gradually replaced by the variable speed ACs due to high energy saving potential and providing comfort at the same time [3].

In Turkey, the number of split type air conditioners, sold in the national market between 2007 and 2011, is about 4.75 million, as stated by Turkish Air Conditioning and Refrigeration Manufacturers' Association (ISKID). According to ISKID, approximately 1 million ACs have been sold in Turkish market in each year, just for mainly cooling purposes in the summer season. Moreover, ratios of variable speed technology and "A" energy class ACs increase from 2.6% to 19.6% and from 29.3% to 87.9% between 2007 and 2011, respectively [4].

In this study, it is aimed to compare the differences between energy consumptions of split type variable and constant speed ACs in the typical public office room, located in Istanbul Technical

University (ITU), Energy Institute for a period of between 31st of July and 1st of October 2012 by using three different analyses.

Test field setup

This field test was conducted in Istanbul Technical University (ITU), Energy Institute building in Ayazaga Campus, Sarıyer. In this building, a test room was selected for the field test. The test room has an area of 24.5 m^2 and height of 3 m where windows are facing to the east. The room was equipped with two AC units. One is a variable speed AC (inverter model) while the other is a constant speed AC (non-inverter model) as seen in Figure 1. The non-inverter AC operates on/off, whereas the inverter AC is produced to operate with a variable speed mode. Table 1 shows the cooling capacity (BTU/h and kW), minimum, nominal and maximum rated powers (kW) and energy efficiency ratio (EER) values of the ACs used in the field test. An energy monitoring system was installed to obtain the required data. In addition a digital time switch was used for shifting the ACs' within a 24 hour period. Temperature logging devices were used for indoor and outdoor temperature measurements. The energy analyser was for collecting date, time, voltage (V), current (I), active (P), reactive (Q) and apparent powers (S) which was set to log the data in 1 min intervals whereas temperature loggers were set to take data in 30 minutes. The set temperatures of ACs' were adjusted according to the users (3 person working in the test room) comfort condition [5].

Figure 1. The test room with inverter and non-inverter ACs

Table 1. The properties of ACs used in the field test [5]

Type	Cooling Capacity		Rated Power (kW) Min./Nom./Max.	EER
	BTU/h	kW		
Inverter AC	10,900	3.2	0.31/0.995/1.43	3.21
Non-inverter AC	12,000	3.52	1.09	3.23

Analysis Method

After collecting the data, three different types of analyses were conducted in order to calculate the energy saving ratio of the inverter AC to the non-inverter AC. First analysis was basically calculating daily energy consumption, containing working days energy consumption values. Secondly the weighted average power values were calculated using the working hours in order to investigate the change in energy saving ratio of AC types. Lastly, for a specific analysis, sample days that have the similar outside temperature pattern were selected and the performance of the inverter and non-inverter ACs were compared. The following subsections describe the calculation methods for the analyses.

Daily Energy Consumption

By using the logged data in 1 minute interval (P_i) in W, daily (E_{Daily}) was calculated by means of Equation 1 [5]. Daily energy consumption means the total energy consumed in 24 hour period for work days excluding the holidays.

$$E_{Daily} = \frac{1}{60}\sum_{i=1}^{24}\sum_{j=1}^{60} P_{ij} \qquad (1)$$

Weighted Power Analysis

Firstly, daily total average powers (P_{ave}) in W for each day in the analysis period were calculated by Equation 2. Secondly, in order to find weighted average power (P_w), which can be defined as the ratio of total energy consumption to the total operated hours (t_i), total operating hours of the ACs at a specified day (t_n) were taken into account as given in Equation 3 [5].

$$P_{ave} = \frac{\sum_{i=1}^{t_i}\sum_{j=1}^{60} P_{ij}}{60 t_i} \qquad (2)$$

$$P_{w_n} = \frac{P_{w_{n-1}}\sum_{i=1}^{n-1} t_i + P_{ave_n} t_n}{\sum_{i=1}^{n} t_i} \qquad (3)$$

Comparative Analyses for Typical Days

In order to compare energy savings of inverter AC over non-inverter AC, sample day couples, which have similar outside temperature patterns for the working hours, were found. For finding the day couples it was checked that whether the room has different AC types (one day inverter, other day non-inverter) or not. As a result, two appropriate typical day couples were identified. Outside temperature patterns of these day couples can be seen from Figure 2 and 3. For these days, equal hours of operation were selected and these are: for 7-8 August as 08:30-17:30 and for 16-17 August 08:30-16:27. Within these working hours, the AC type (inverter/non-inverter), average active power (P_{ave}), operational energy consumption (E_{opr}) which is energy consumed in the hours in which ACs are in operation, the minimum/maximum and average value of outside temperature values were compared.

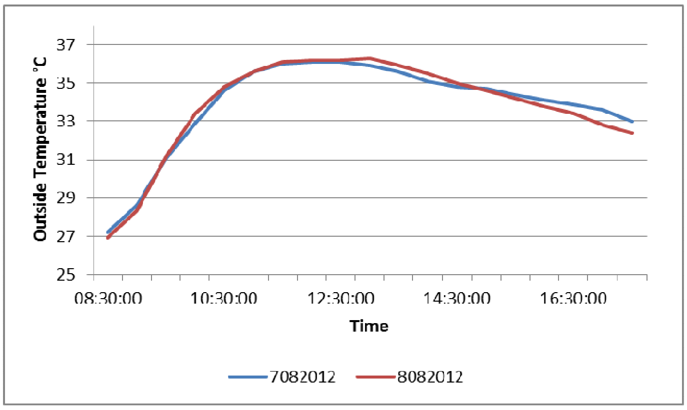

Figure 2. Outside Temperature Pattern for 7-8 August 2012 [5]

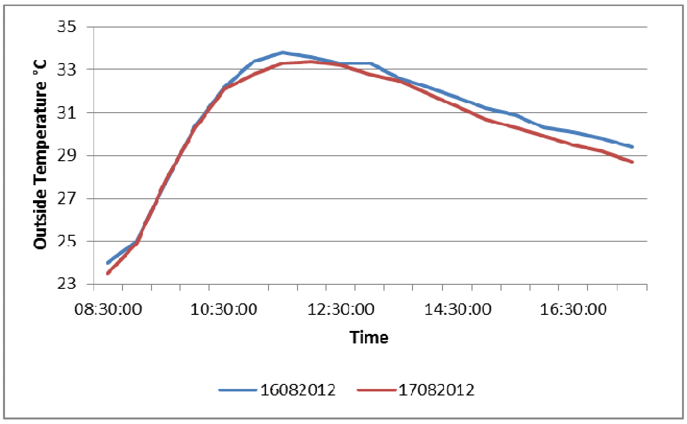

Figure 3. Outside Temperature Pattern for 16-17 August 2012 [5]

Results

Daily Energy Consumption

In this field test, which is in between 31st of July to 1st October excluding holidays, ACs were operated for 42 days. The number of working days for inverter and non-inverter AC was 21 for each of them and Figure 4 represents daily energy consumptions for the test room.

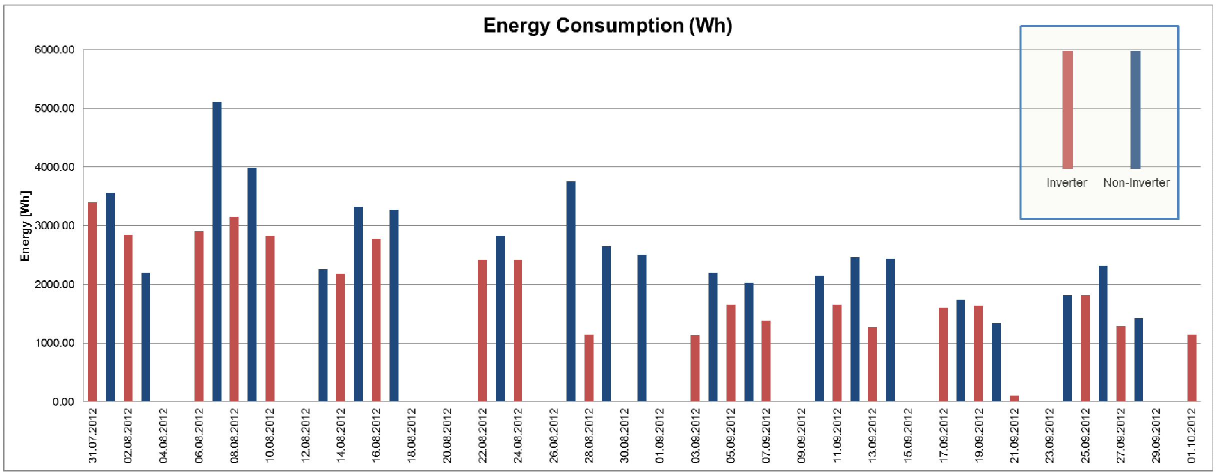

Figure 4. Daily energy consumption of working days for the test room

The daily energy consumptions for inverter and non-inverter ACs are 40,779.77 Wh and 55,381.91 Wh, respectively. In other words, inverter AC consumes approximately 26% less energy as compared to non-inverter AC for the test room.

It is also worth to mention that the stand-by power values for inverter AC is 4.3 W and for non-inverter AC is 2.1 W. Since the test room was a public office, the working hours in a day were usually in between 8:30 and 17:30 meaning that 15 hours ACs are in stand-by mode.

Weighted average power analysis

Daily and weighted average powers for inverter and non-inverter ACs were calculated from the Equations 2 and 3 and sketched for daily basis, as can be seen from Figure 5 and 6, respectively.

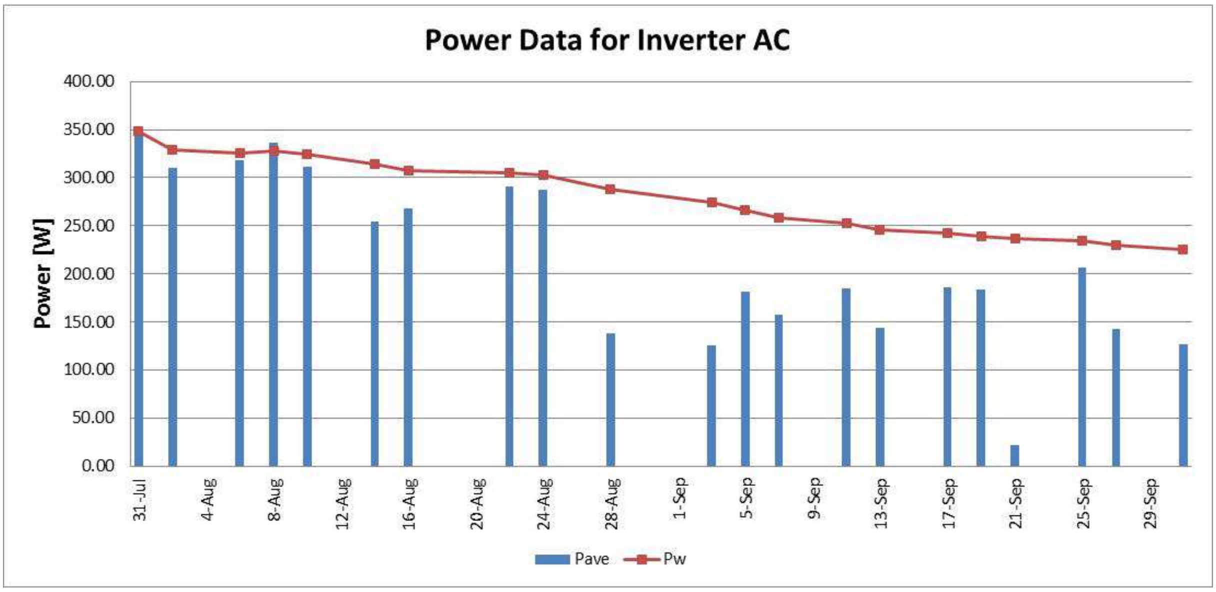

Figure 5. Daily and weighted average power graphs for inverter AC [5]

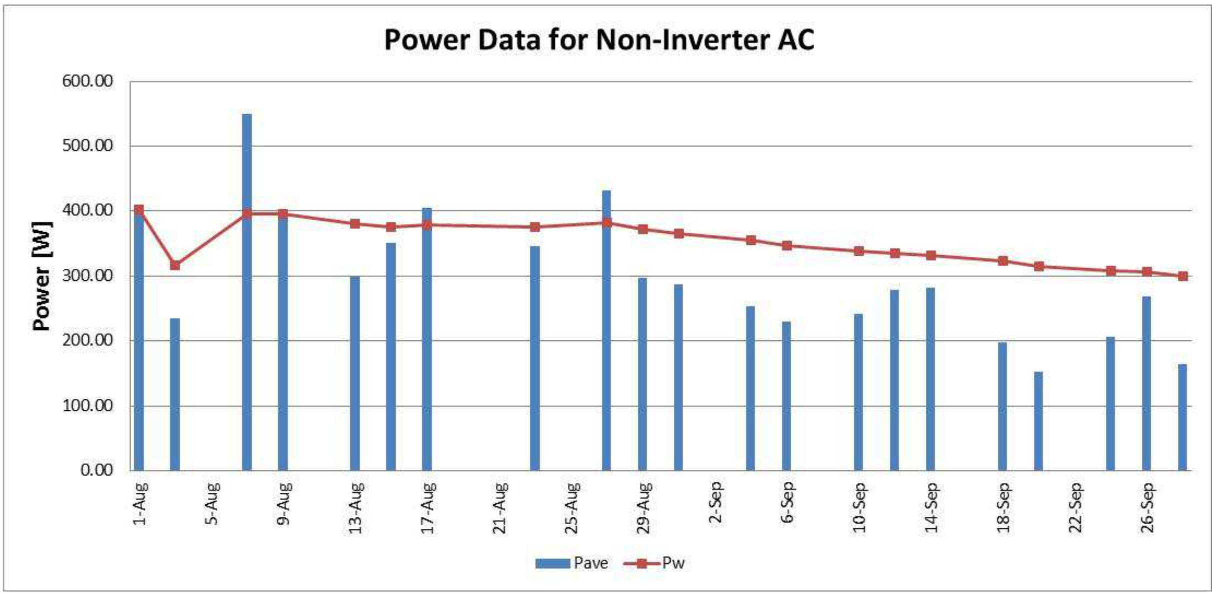

Figure 6. Daily and weighted average power graphs for non-inverter AC [5]

The weighted average power for inverter AC was calculated as 225.38 W whereas it was 300.08 W for non-inverter one. Energy saving ratio obtained by this analysis is about 25%.

Comparative analyses for selected typical days:

This analysis was conducted to compare inverter and non-inverter ACs within the test room concerning the similar outside temperature patterns. The results can be seen from Table 2 and changes on the observed parameters were presented in Figure 7 and Figure 8 for the selected day couples.

Table 2. Comparison of inverter and non-inverter ACs for 7-8 and 16-17 August 2012 [5]

Date	**07.08.2012**	**08.08.2012**	**16.08.2012**	**17.08.2012**
Ac Type	Non-Inverter	Inverter	Inverter	Non-Inverter
Operation Hours	08:30 – 17:30		08:30 – 16:27	
P_{ave} [W]	543.4	334.7	260.6	404.9
E_{opr} [Wh]	4888.0	3012.1	2075.9	3225.4
E_{saving} [%]	**38%**		**36%**	
T_{out} Min	27.2	26.9	24	23.5
T_{out} Max	36.1	36.3	33.8	33.4
T_{out} Average	33.9	33.8	30.8	30.4

For the first day couple (07-08 August 2012) the energy saving ratio of inverter AC over non-inverter AC is calculated as 38% and for the latter (16-17 August 2012) it is 36%. When these values are compared to the results of the first two analyses, it can be claimed that if the ACs are operated near to full capacity condition, it means that cooling demand is high, energy saving potentials increase.

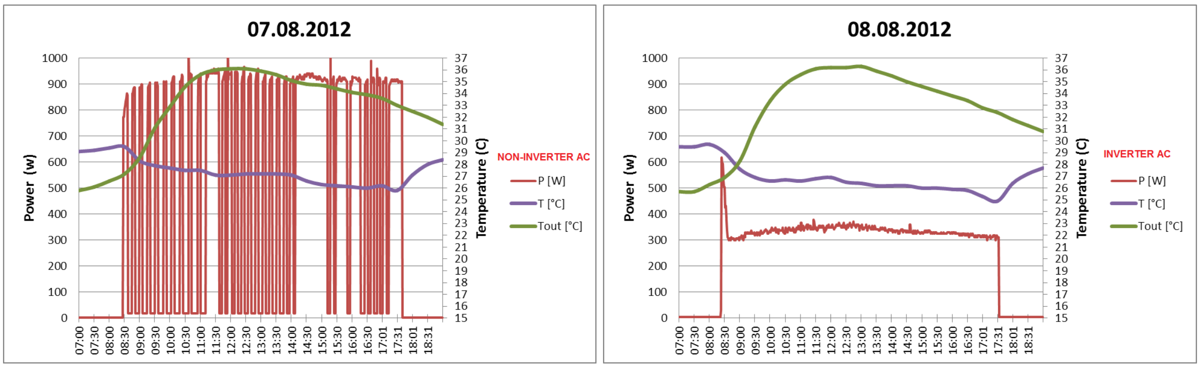

Figure 7. Changes in inside, outside temperatures together with 1 min power data for the test room (07– 08 August 2012)

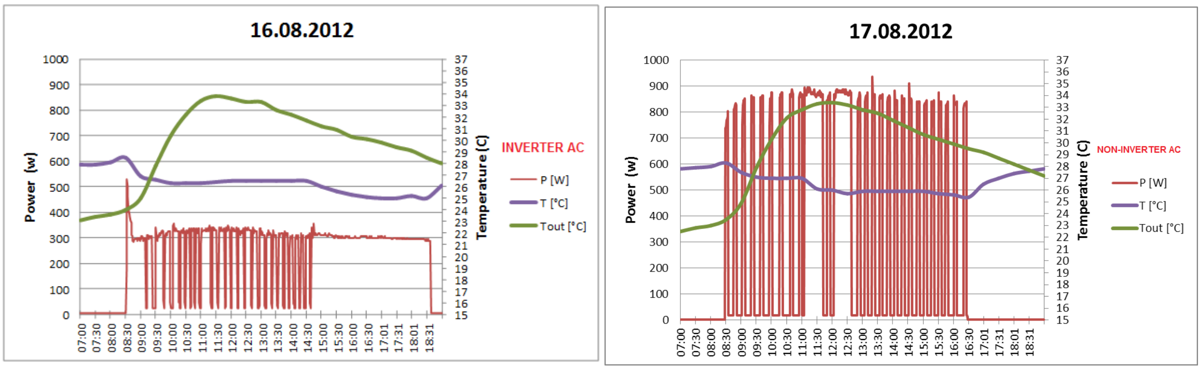

Figure 8. Changes in inside, outside temperatures together with 1 min power data for the test room (16-17 August 2012)

Conclusion

This field test was realized for comparing energy consumptions of inverter and non-inverter ACs in a typical public office room in İstanbul for a selected cooling period (31st of July, to 1st of October 2012). When energy consumptions of inverter and non-inverter ACs are compared by using different calculations methods, the results show that the inverter technology is more favourable and yields high efficiency for the climates with varying temperatures in a day. One of the main observations is that for selected inverter AC type, lower cooling loads than minimum rated power results in shifting inverter

AC to on/off mode like a non-inverter AC. As a result, inverter AC with the wider range control seems to be needed for lower cooling loads.

EER is usually used as an indicator for evaluating cooling efficiencies of the ACs. In this field test, it is seen that energy consumptions of inverter ACs and non- inverter ACs are different from each other although their EER values are almost the same for selected two ACs as mentioned before. In parallel with EU Ecodesign Directive (2009/125/EC) [6], in Turkey, Ministry of Science, Industry and Technology (MoSIT) published “Regulation on Ecodesign of Energy Related Products” on 7 October 2010 [7]. Within the framework of this regulation, “Notice on Ecodesign of Air Conditioners and Ventilators” were prepared and published by MoSIT in 19 July 2013 and this notice introduced Seasonal EER (SEER) and Seasonal COP (SCOP) concepts [8]. Nonetheless, ISO has introduced a new indicator, Seasonal Performance Factor (SPF), explained in ISO 16358-1:2013 standard [9] which additionally utilizes the load conditions of the buildings, the utilization purpose of ACs, outside air temperature in the cooling period and ACs’ efficiency depending on the variable capacities instead of just comparing energy consumption of the ACs. Therefore, this new development can be regarded as very hot topic to work on when comparing the energy saving ratios of ACs.

Acknowledgement

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Advanced trigeneration plant in a District Heating and Cooling network of a Science and Technology Park

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Abstract

In this paper is presented the configuration, operation and practical experience of an advanced trigeneration plant connected to a District Heating and Cooling (DHC) network that provides electricity, heating and cooling to a Science and Technology Park called Parc de l'Alba in Cerdanyola del Vallès (Barcelona, Spain). The main facility of the Science and Technology Park is a Synchrotron Light Facility but also includes office buildings among other public and private buildings. In a first stage, which culminated in late 2010, the landmark science and technology facilities came into service and the planning of the green zones was defined. After that, the first blocks of public and private housing will be built. A section of the park is devoted to accommodate data centres (Data Processing Centre). The residential area is not included in the DHC network since its demand profile does not justify the additional investment required. The trigeneration plant is based on three natural gas cogeneration engines of 3.35 MW each one able to produce electric power and heating and also chilled water using two absorption chillers. One of them is a single-effect chiller of 3 MW using the cooling water from the engines and the other is one of the few directly exhaust gas-fired double effect chillers in service in Europe. This unit has a chilled water capacity of about 5 MW at nominal conditions. All these facilities are described in detail in the paper and the first energy performance analysis will be presented for the monitored operation periods.

Introduction and objectives

Trigeneration systems refers to highly efficiency integrated systems characterized by the simultaneously production of different services (electricity, heating, cooling, water, etc) by means of several technologies using fossil and/or renewable energy sources to obtain a higher efficiency than that of an equivalent conventional system. Trigeneration should be regarded as a particular type of polygeneration plant [1] or multienergy system [2]. In many cases it is difficult to promote trigeneration projects due to its complexity. This complexity mainly comes from the high energy integration of the technologies involved and the high variability in the energy demand, especially in many applications in the building sector that makes the design and optimal operation of these systems quite complex [3].

Thus it is important a careful design, planning and optimal operational strategy of these systems in order to obtain economic benefits, to supply the energy demand to the users, and to obtain higher efficiencies than those of conventional alternatives [4]. This paper presents the design and operational results of a modular trigeneration plant [5] located in a technological park in Cerdanyola del Vallès (Spain) in the framework of the Polycity project of the European Concerto Program [6].

In the framework of the Polycity project a high efficiency energy polygeneration system was implemented in a new urban development called Parc de l'Alba. This area includes a Science and Technology Park. The main facility of this Science and Technology Park is a Synchrotron Light Facility but also includes office buildings among other public and private buildings. In a first stage, which culminated in late 2010, the landmark science and technology facilities came into service and the planning of the green zones was defined. After that, the first blocks of public and private housing will be built. A section of the park is devoted to accommodate data centres (Data Processing Centre). The residential area is not included in the DHC network since its demand profile does not justify the additional investment required. The trigeneration system provides electricity, hot and chilled water for the Synchrotron and the technological park buildings through a four-pipe district heating and cooling network connected to the final users. This system comprises high efficiency natural gas engines driving thermal and compression cooling facilities.

As these new urban area is under development, several phases have been planned including several trigeneration plants including renewable energy sources and the expansion of the district cooling and heating (DHC) network. The first phase comprises the ST-4 plant and its DHC network providing hot and chilled water mainly to the synchrotron. The objective of this paper is to present the configuration, operation and practical experience of an advanced trigeneration plant connected to a District Heating and Cooling (DHC) network that provides electricity, heating and cooling to a Science and Technology Park called Parc de l'Alba in Cerdanyola del Vallès (Barcelona, Spain).

Description of the trigeneration plant and DHC network

Trigeneration Plant

Initially due to the low occupancy of the park, the ST-4 plant was conceived using a modular design that allows extending the plant when energy demand grows up. ST-4 plant is composed of three gas cogeneration engines of 3.35 MW each one, a direct fired exhaust gas absorption chiller of 5 MW and a COP=1.3 using directly the engine exhausts gases, a single-effect absorption chiller of 3 MW and a COP=0.7 recovering heat from the engine jacket cooling, a compression chiller of 5 MW and a COP of 5.8, a natural gas boiler of 5 MW and a chilled water storage tank of 4000 m^3. A simplified scheme of the ST-4 plant is presented in figure 1 and in figure 2 is presented an external and internal picture of this plant.

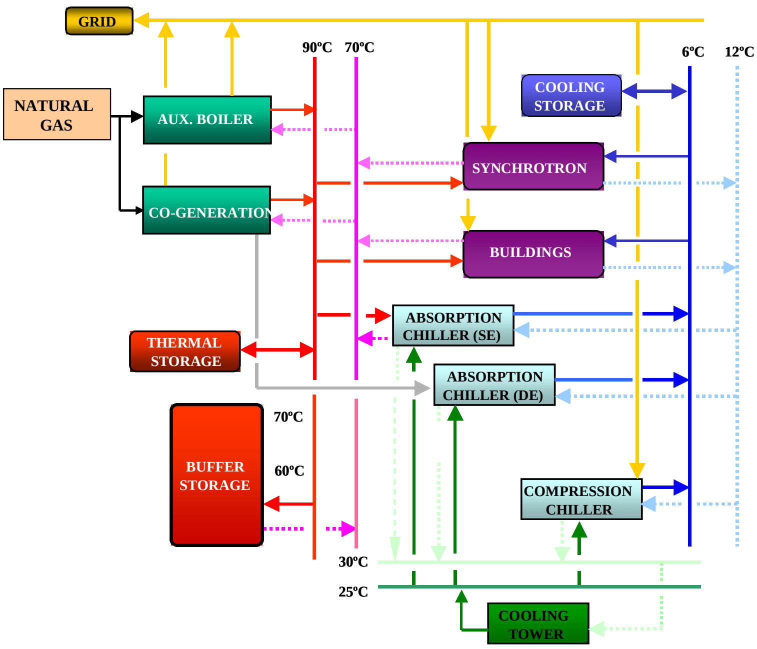

Figure 1 Schematic of the ST-4 trigeneration plant

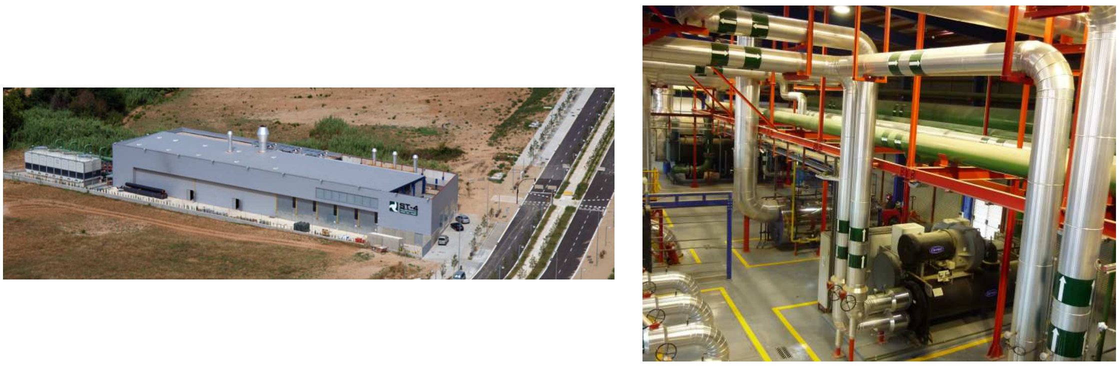

Figure 2 External view of the ST-4 plant and view of the Chiller and boiler room

The three cogeneration engines produce electricity (mainly sold to the grid) and wasted heat recovered from the hot water jacket circuit and the exhaust gases. Figure 3 shows the energy flow of each cogeneration engine at rated conditions.

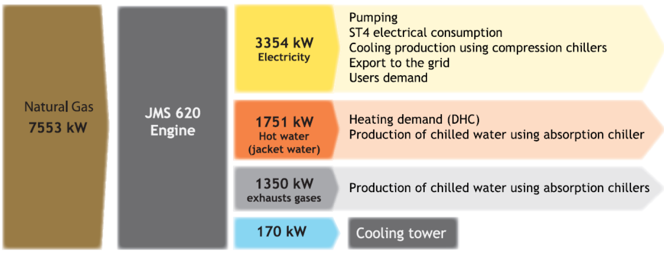

Figure 3 Energy flow of each cogeneration engine at rated conditions

The waste heat recovered from the jacket water circuit of the engines is used to produce hot water for the district heating network and to drive a simple effect (SE) water/LiBr absorption chiller of 3 MW of cooling. As a function of the chilled water demand and the operation conditions of the ST-4 plant, some of the exhausts gases pass through the double effect (DE) water/LiBr absorption chiller of 5 MW of cooling to produce more chilled water. When the DE absorption chiller is not in operation, no heat is recovered from the exhausts gases. At rated conditions, the DE absorption chiller requires the exhausts gas flow rate of the three engines and the part load operation of the chiller is controlled by regulating the amount of exhausts gases passing through the chiller. This chiller is one of the few units in service in Europe driven directly with exhaust gases. The energy balance of the SE and DE chillers working at full load is shown in figure 4.

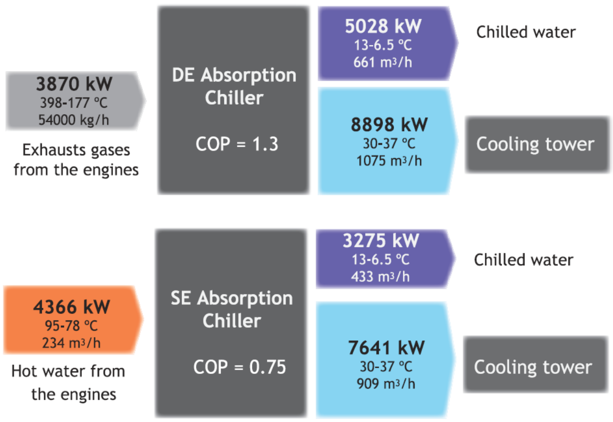

Figure 4 Energy flow of the DE and SE absorption chiller at rated conditions

A backup boiler and a compression chiller produce hot and chilled water respectively during very low energy demand periods (at night and during the weekends, periods in which the engines are not in service). An underground chilled water storage tank enables the plant to shift demand peak loads. The tank can hold up to 4,000 m^3 of water thus it could provide 7 MW for 2.5 hours with a temperature difference of 6ºC. A plate heat exchanger is used to charge or discharge the tank to the cooling network. This system was designed to cover the cooling demand during night time and weekend periods.

For economic reasons the three engines are working only during the day, but the operation can be adapted as a function of the users demand (working with the required number of engines). In the same way, the recovery of heat from the engines, and the production of chilled water with the chillers are done as a function of the hot and chilled water demand. One, two or all chillers can work to cover the users demand. The underground chilled water storage tank adds flexibility to the operation of the plant, storing chilled water during the day and supplying chilled water during the night.

Due to the initial low energy demand, the ST-4 plant has been designed in a modular way allowing the addition of more units as the energy demand grows. The plant can hold up to 5 cogeneration engines of the same size that the existing ones, two DE absorption chiller driven by the exhausts gases of the engines, and two SE absorption chillers driven by the hot water produced with the engines. The enlargement of the plant will allow not only to increase of the energy production of the plant, with the connection of more users to the DHC, but also to increase the energy savings obtained with the operation of the plant. When considering the plant totally expanded, it is expected to achieve energy savings up to 25% under rated conditions [7, 8] with respect to state of the art conventional energy supply systems. Figure 5 shows the energy flow of the ST-4 plant considering all the future expansions.

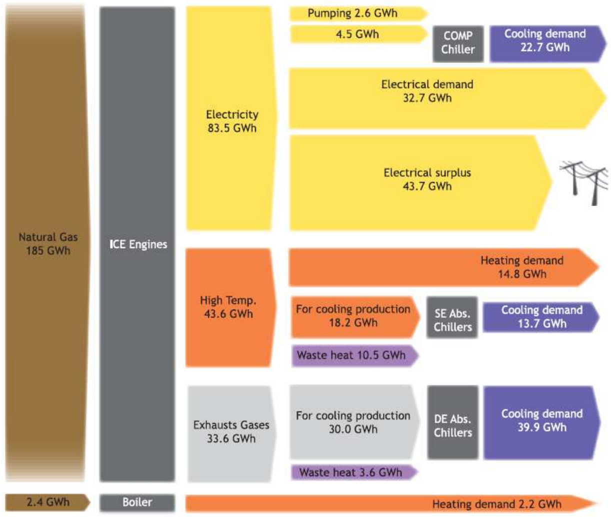

Figure 5 Energy flow for the ST-4 plant totally expanded

DHC Network

A DHC Network usually consists of a pipeline system to transport heat and cooling from a energy plant to several final users. The possibility to use high efficiency energy generation systems using different technologies with heat recovery is the main advantage with respect to using a centralized energy production system based on the public grid and the rejection of heat to the ambient. The current evolution from these centralized systems to energetically independent smart cities makes DHC networks the ideal solution for many new urban developments.

The first stage of the DHC network at the Parc de l'Alba is already in service. It is a 4-tube network with a total length of 15.3 km. The design supply and return temperatures for chilled water are 6 / 13ºC and 90 / 75ºC for the case of the hot water. The Synchrotron building is the main user of the system and has been connected directly to the trigeneration plant for the chilled water supply with a DN500 (508/630 mm) preinsulated pipe, with diffusion barrier and built-in surveillance system. For the case of the hot water a similar DN150 (168 /250 mm) pipeline is used. The total pipeline length for both services is the same, 770 m [5].

Preliminary evaluation of the operational performance

An acquisition system was installed in order to register process variables from the plant control system such as mass flow rates, temperatures, capacities, internal variables of the main units. These values are recorded each minute and used to evaluate the performance of each unit and the whole plant. The operation of the plant started in 2010 and since then the data acquisition system has been working, but due to technical problems some of the data was missing. The first monitored results (2010-2011) showed an important difference between the expected energy demand (calculated in 2008 when the ST-4 plant was just designed) and the real one when the plant started. Due to the adverse economic situation the real energy demand is much lower than the initial expected energy demand. This behavior has continued during the following years (2012 and 2013). Due to the low energy demand the ST-4 plant is working at very low part load with respect to the rated conditions decreasing the overall efficiency of the plant.

Almost all the engines electrical production is sold to the grid. Under normal operation conditions the engines work with a constant time schedule for economic reasons. The monthly electricity production is quite constant (Figure 6). The periods with a lower electric production are due to missing monitored data for a particular month. The three engines run almost at full load along the whole year. In this case the electricity production is about 3220 MWh/month.

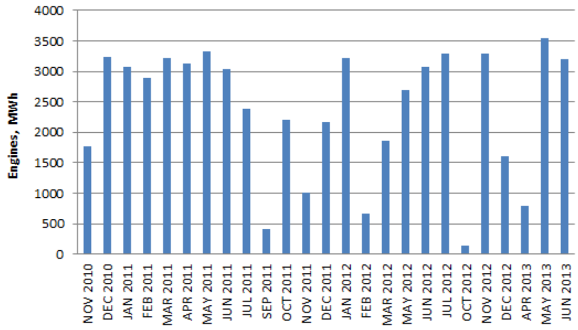

Figure 6 Electrical production of the cogeneration engines

Figure 7 shows the monthly average electrical efficiency of the engines. As shown in this graph the efficiency is about 43% or higher. The global efficiency including the recovered heat is about 70% or higher. A group of air coolers is used when the heating demand is very low and exceeds the heat contained in the engine cooling jacket system.

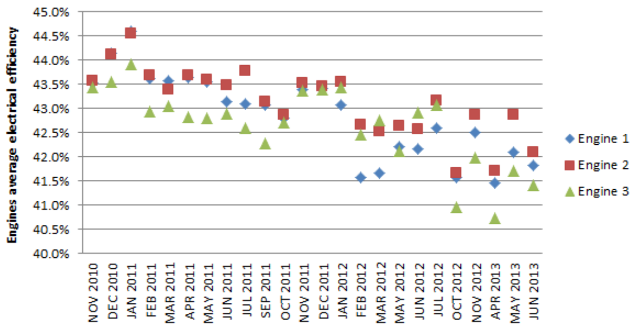

Figure 7 Electrical efficiency of the cogeneration engines

Figure 8 shows the total chilled water production of the plant. Months with very low production are due to missing monitoring data. From this figure it can be seen a higher energy demand in 2012 (for example June – July 2012) with respect to 2011 (May – June 2011). Despite this slight increment, the demand is still very far from the capacity of the plant. Compression chillers are used to supply the chilled water demand during the weekends (when all the other units are not in operation) or as backup when one of the absorption chillers is not in operation.

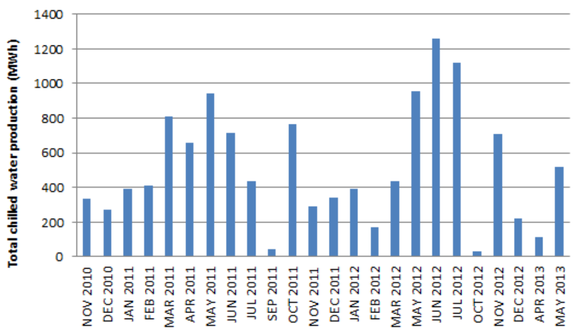

Figure 8 Monthly chilled water production

The chilled water is produced at a quite low temperature as shown in Figure 9 due to the user demand requirements, the necessary storage of chilled water and the losses in the district cooling network. The monthly average chilled water produced with the SE absorption chiller is below 5 ºC, and around 5.5 ºC for the DE absorption chiller. In order to analyze the COP of the absorption chillers, cooling water temperature and the activation temperature are also important. Figure 10 shows the monthly average temperature of the hot water generated by the engines. This temperature is about 86ºC within a range between 82-92ºC. This hot water is used to supply the heat demand of the user and to drive the SE absorption chiller. As the temperature of the hot water recovered from the engines increases the heat losses increase in the DH network but the COP in the SE absorption will be higher. Due to several problems the energy demand is quite low compared with the installed capacity.

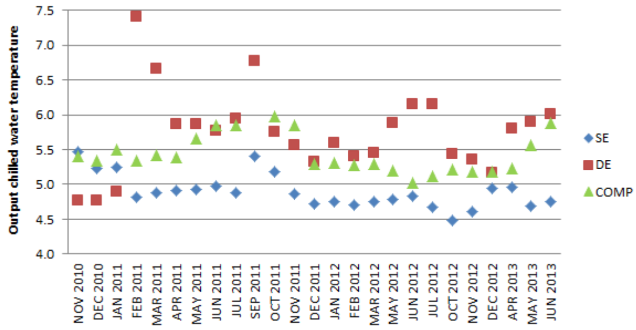

Figure 9 Output temperature of the chilled water

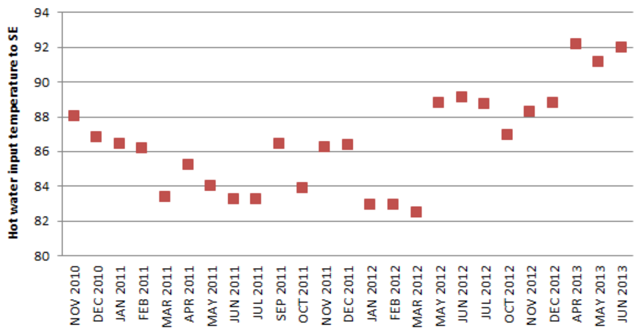

Figure 10 Output temperature of the hot water

The driven temperature of the DE absorption chiller is quite constant. At nominal conditions the output temperature of the exhausts gases of the cogeneration engines is around 380 ºC. The part load operation of the DE absorption chiller is controlled by regulating the amount of exhausts gasses passing through the chiller. Figure 11 shows the monthly average COP of the SE and DE absorption chillers, respectively. It is important to notice that the COP of the SE chiller is only slightly lower that the nominal value especially taking into account that the unit has been working between 20% and 40% of its full capacity. The same is true for the DE chiller that has been running between the 20% and 70% of its full capacity.

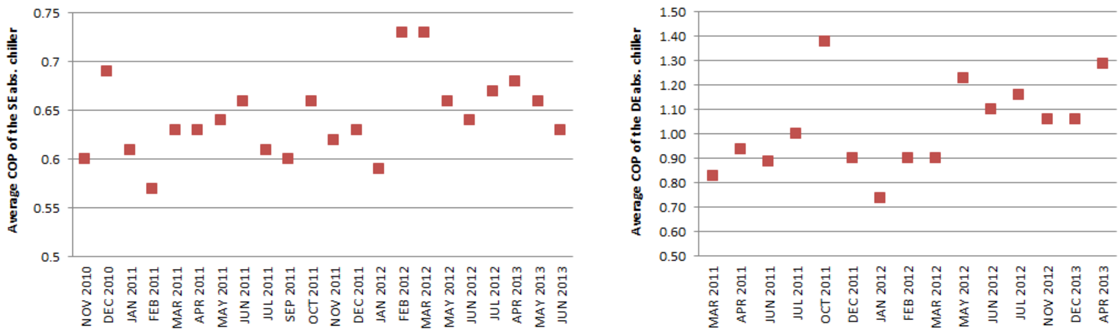

Figure 11 COP of the SE and DE absorption chiller

Conclusions

In this paper it is presented the first preliminary operation analysis of a modular trigeneration plant composed of high efficiently cogeneration engines and two types of absorption chillers among others units. The main relevant features of this plant are the use of cogeneration engines with a high electrical efficiency up to 44% and the use of exhausts gases directly to drive a double effect absorption chiller. The hot water from the engines can be used to cover the heating demand and to produce cooling by means of a simple effect absorption chiller. An underground chilled water storage tank allows coupling the chilled water production with the demand. Considering rated conditions the plant will be able to save up to 25% of primary energy with respect to a conventional energy supply system. The present low energy demand affects the heat recovery from the engines and the chillers work at partial load. Energy savings will increase with the future increase in energy demand.

The ST-4 energy plant can be expanded if more users get connected in the future and the energy demand grows. Due to the low energy demand, the operation schedule of the plant engines is fixed in order to assure economic benefits. In spite of the still low energy demand, the efficiency of the absorption chillers is still quite high contributing to the plant viability from the beginning of the project characterized by a low energy demand.

In the coming months a complete primary energy saving analysis using hourly operational data will be performed as soon as the energy demand will be higher with the expected increase of activity in the Science and Technology Park. The results could be the starting point for the operational optimization of the trigeneration plant and DHC network as a whole.

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Assessing the energy performance in the tertiary building sector. On-site monitoring of large-scale retail chain.

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Abstract

The paper addresses the challenges of monitoring and benchmarking the energy performance of HVAC systems and other electric loads in the tertiary building sector. This information is necessary in many areas to enable the recast EPBD to achieve its full impact in reducing energy use in Building Technical Systems. The analysis covers hourly data analysis and benchmarking based on monthly data. The collection and processing of energy performance data could be part of the inspection of HVAC systems, aimed at identifying technically feasible and cost-effective Energy Conservation Opportunities (ECO's), as required by EPBD.

The paper is based on the IEE iSERVcmb project (www.iservcmb.info), which intends to monitor, for periods of at least a year, the sub-hourly energy consumption of 1600 HVAC systems installed in buildings around the EU Member States. One of the main aims of the project is to produce ranges of benchmark performance for the energy use of HVAC systems and components relative to the activities that are being served. The paper presents the pros and cons of existing benchmark schemes for HVAC systems, and discusses the strategy to be adopted for the production of these iSERVcmb HVAC energy consumption benchmarks.

Introduction

Energy efficiency in buildings is definitely arising as a primary energy conservation tool on the path of sustainability of cities and human agglomerates. Air conditioning systems can account for up to 50% of the energy used in a building, and have therefore been specifically targeted by energy legislation in the last decades. The last Energy Performance of Buildings Directive (EPBD), published in 2010, requires regular inspection of air-conditioning systems [1]. While it is evident that a well controlled and maintained HVAC system is more efficient than a poorly controlled and maintained one, it is not proved that Inspection alone can ensure such conditions. In Europe, IEE Harmonac project shows that HVAC inspections, even if developed with a high level of detail, are not sufficient to ensure system efficiency. In addition, the presence of a Building Management System (BMS) is not a sufficient condition to achieve a satisfactory HVAC system efficiency. To reach this result, the BMS needs a correct design and commissioning, a frame dedicated to energy monitoring and a properly instructed operator.

ISERVcmb project, funded by European Commission in the framework of Intelligent Energy for Europe program (IEE), is mainly focus on HVAC system consumption. The basic idea is that a well monitored system would allow more specific inspections and energy audit and, in addition, gives the possibility to decrease mandatory inspections frequency. The project is intended to collect energy consumption data from end users (building owners and managers) continuously: it was possible to collect data from different tertiary sector buildings at a 15 minutes frequency (mainly electric consumption of different loads). In this paper we focused on the large-scale retail channel buildings. We were able to collect hourly data of electric consumption, disaggregated by different loads. Data acquired permit to verify actual control of lighting and HVAC systems (Diagnosis) and to compare building consumption on a monthly and annual basis (Benchmarking).

To improve efficiency of Heating, Ventilation and Air Conditioning (HVAC) systems, it is essential to understand which are the energy conservation opportunities (ECO) with the best benefit/cost ratio. Intending the ECO as a large group of actions (from changing the schedule to replacing the main chiller/boiler) an adequate statistical basis of data is needed, in order to understand which part of the system is more consuming and which part could be improved with small effort. In the past twenty years a large number of papers about energy consumption in buildings were written; nevertheless a comprehensive and accepted specific set of data on energy uses for different activities in the tertiary sector is still lacking. The main reasons for this lack of data are mainly linked to data collection. Due to the variety of building and HVAC systems, it is difficult to standardize collected data, on the other hand end users are often reluctant to provide their energy consumption data.

Data acquired and Buildings

Consumption data were collected by in situ electric meters installed in the main electrical boards. Due to the design of electric system, sometimes more electric meters are needed to measure a specific load (is the case of lighting, often partially served by UPS). Electric meters are nowadays quite cheap (300-600 € + Installation costs), nevertheless the cost of data acquisition and analysis is still variable and relatively high (200-500 € per year per meter). The large-scale retail channel company analyzed has around 200 buildings in Italy, with around 30 Large-scale retail buildings (building with more than 6’000 square meters of Gross Internal Area, GIA). Twenty of those buildings are monitored, while we focus on 9 buildings (Table I). In some of those buildings was not installed specific load metering due to complexity of electric panel and electric distribution: to collect all the lighting lines could be necessary more than 10 electric meters. This implies that for some buildings we had just some specific load metered (Figure 1).

The buildings share the design of space distribution and activities: typically the main sale area is surrounded by specific food preparation area such as bakery, fish shop, grocer’s, etc. The main sale area has refrigerated cabinets served by two centralized systems. One system serves food refrigeration at 20°C, while the other serves food refrigeration at +4 °C. Both systems have reciprocating electric compressors and are air condensed.

All the buildings analyzed are served by air HVAC system based on rooftop units. Some buildings have gas boilers and air condensed chillers that provide respectively hot and cold water to the rooftop heat exchangers. In some case the rooftops have a gas boiler and an electric chiller onboard. The buildings are open 7/7 for the whole year, and the working hours are typically from 09:00 AM to 09:00 PM.

Table I:Yearly specific consumption of different electric loads (kWh/m2)

SHOP	LOCATION	SALE AREA (m^2)	LIGHTING	Refrigeration (4°C)	Refrigeration (-20°C)	HVAC	OTHER LOADS	TOTAL
A	Teramo	8877	69.8	47.3	12.2	81.3	279.5	490.1
B	Monza	7250	N/A	86.9	41.8	100.3	460.3	689.3
C	Pavia	12576	172.4	N/A	35.1	17.7	218.7	443.8
D	Udine	7000	38.7	51.1	16.4	45.1	348.8	500.0
E	Cesena	13000	54.2	57.8	46.2	55.7	195.3	409.2
F	Milano	5403	123.2	93.5	57.2	97.8	458.5	830.2
G	Pescara	8123	72.2	52.8	18.4	37.5	352.4	533.2
H	Chieti	5900	72.7	16.8	35.5	17.5	414.6	557.0
I	Bergamo	13400	N/A	55.6	19.9	62.9	399.3	537.7
mean		9058.8	86.2	57.7	31.4	57.3	347.5	554.5
std.dev.		3132.7	46.1	23.9	15.5	31.2	97.9	130.1

Yearly data show a moderate variability of global electric specific consumption among the different shops. The variability is high for HVAC and other systems, demonstrating that electric consumption could not be forecasted just based on square meter of sales area (other typical factors affecting consumption are occupation, climatic conditions and internal loads).

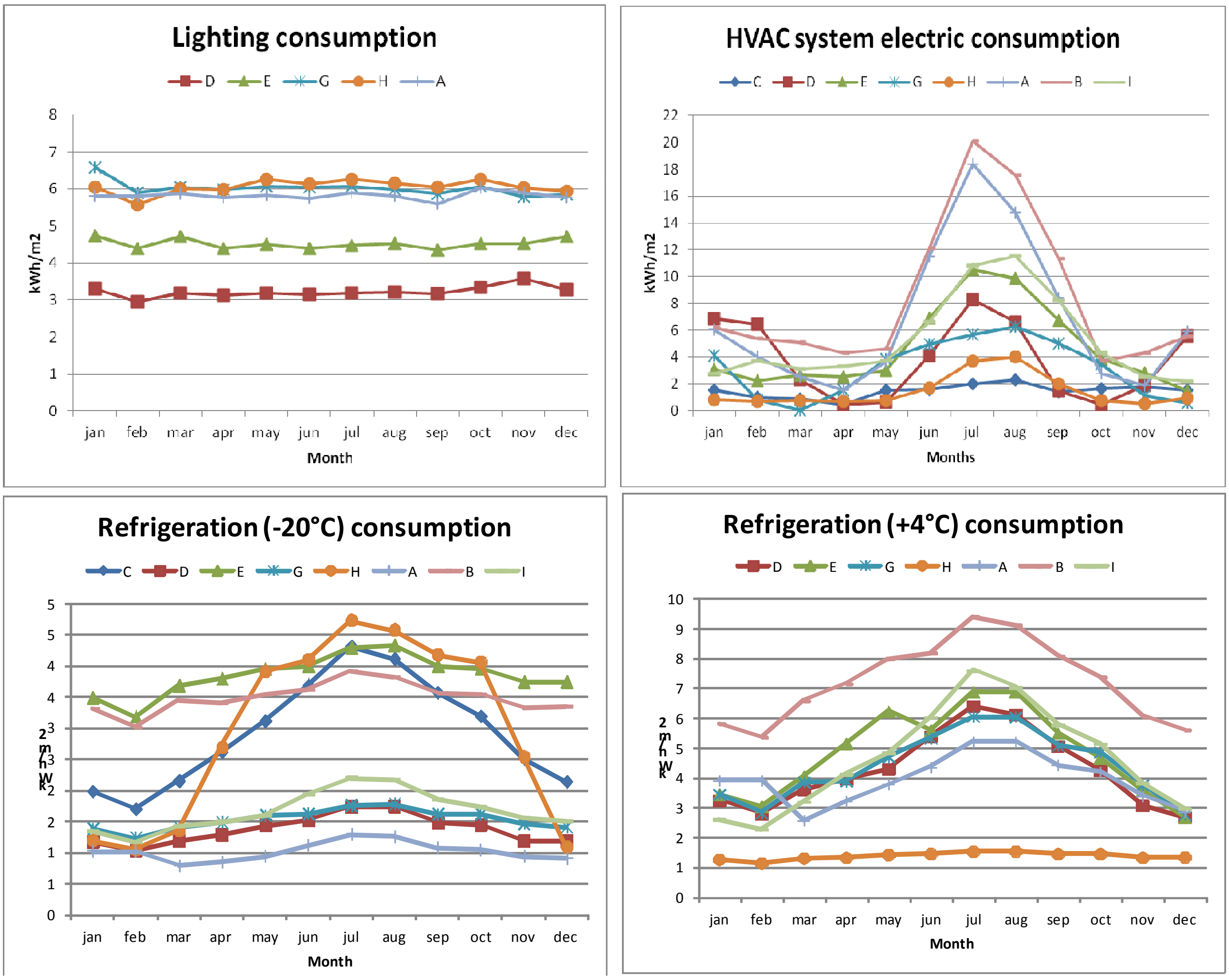

Figure 1: Monthly specific consumption of different electric loads (kWh/m2)

Monthly consumption analysis shows different behaviors for specific loads, depending on climatic conditions and working days (Figure 1). The lighting consumption shows an almost constant behavior, demonstrating that the buildings analyzed do not have automatic control of light flux. Since the average consumption is about 86 kWh/m^2 per year the possibility to dimmer the lighting power in accordance with measured light intensity has to be evaluated. HVAC system consumption shows the highest variability, as expected, demonstrating that the systems control are working at least sufficiently, decreasing the consumption during the middle season. Two of the buildings analyzed show exceptional high consumption during summer. The A building is situated in the center Italy (42°52' N), while the B building is located in the northern Italy (45° 35' N). The high consumption is related to the specific condition of the Chiller units, which suggests an inspection and verification.

Food refrigeration systems have different behaviors. Taking into account food refrigeration at -20°C, generally the consumption is relatively stable, except for the building situated in location with high temperature difference from Summer to Winter. Food refrigeration at 4°C is more affected by external conditions. That as to be expected, since the temperature difference between the condenser and evaporator will vary more in food refrigeration at 4°C system than in the food refrigeration at -20°C. In the graph are clearly visible two buildings with anomalous consumption. H building shows extreme low consumption, if compared with the average, which could imply a small amount of food refrigeration at -20°C cabinet in respect of sale area. On the other hand B building shows higher consumption than the average: it has to be analyzed if this is due to the number of cabinets or to a poor efficiency of the system.

Method

Hourly Data analysis

Data availability permits to define to type of analysis. On the beginning it's possible to evaluate if the hourly consumption of specific load shows possible energy conservations opportunities. In the supermarket activities specific inefficiencies was addressed, concerning HVAC system, food refrigeration system and lighting. This type of analysis, using carpet plots shows in a qualitative ways the frequency of inefficiencies along the weeks.

It is also possible to verify the results of different type of refurbishment or retrofitting. In this paper we will show the effect of glass covering of the refrigerated cabinets.

Monthly Data analysis

To define a possible benchmarks for electric consumption, of specific loads, in the supermarket activities, we define a method to normalize the HVAC consumption in respect of different variables. Generally the variables needed are [2,3]:

- Internal gross area
- External climatic conditions
- Working hours
- Type of HVAC system

In our study we do not consider as an input variable the HVAC system, because we want to visualize the difference between different systems. On the other hand we consider has an input the internal electric loads, to better define the consumption due to HVAC system. To do that we utilize a simple Multiple Linear Regression, in its typical form:

$$E(Y \mid X) = \alpha + \beta_1 \mathrm{X}_1 + \beta_2 \mathrm{X}_2 + [...] + \beta_n \mathrm{X}_n$$

We define a model without internal electrical load (3 variables model) and one with internal electrical load (4 variables model).

Results of hourly analysis

This section will show hourly data analysis for specific loads of some buildings. Some sample, among the most representative, were chosen.

HVAC consumption verification

As seen in the monthly analysis, two buildings (A and B) present exceptionally high consumption during summer. With the hourly data it is possible to check if this is due to poor schedule control or to efficiency/system layout. As shown in further figure, the schedule control appears to be correctly related to working hours. It is possible to determine that the specific HVAC system has a poor efficiency with respect to the other buildings. The hourly analysis of the B building HVAC system shows the same result.

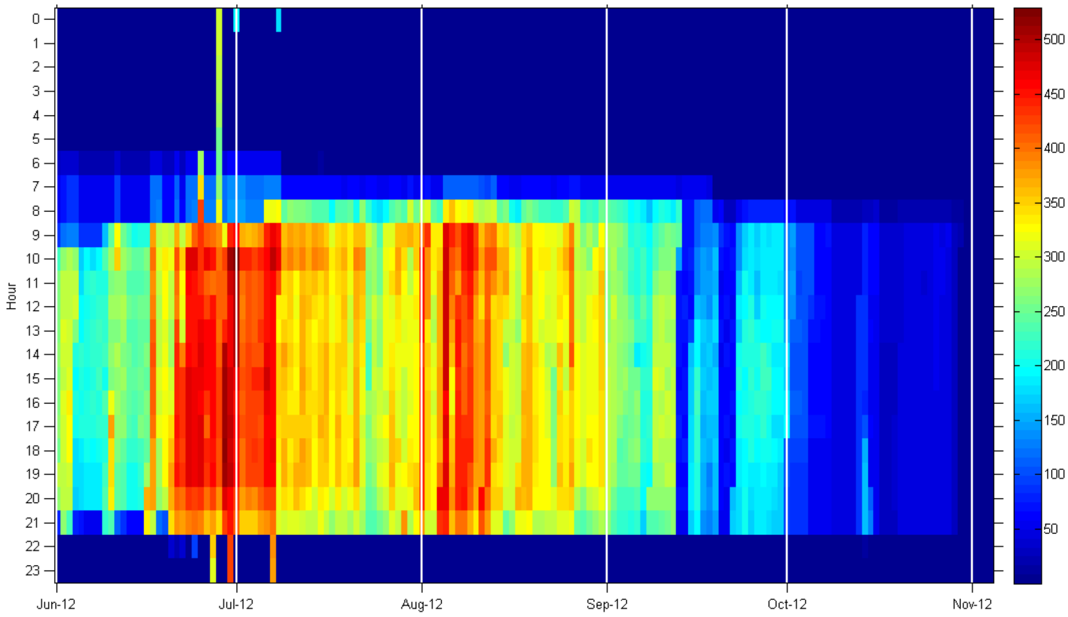

Figure 2: Rooftop electric consumption of building A (kWh)

Lighting efficiency

As for the HVAC system, also in this case is possible to evaluate if the schedule or the system is efficient. Data show that the cause of inefficiency are mainly two:

1. Poor schedule control
2. High base load

In the first case the schedule is not well controlled during night, causing consumption even in non-working hours, as seen in Figure 3.

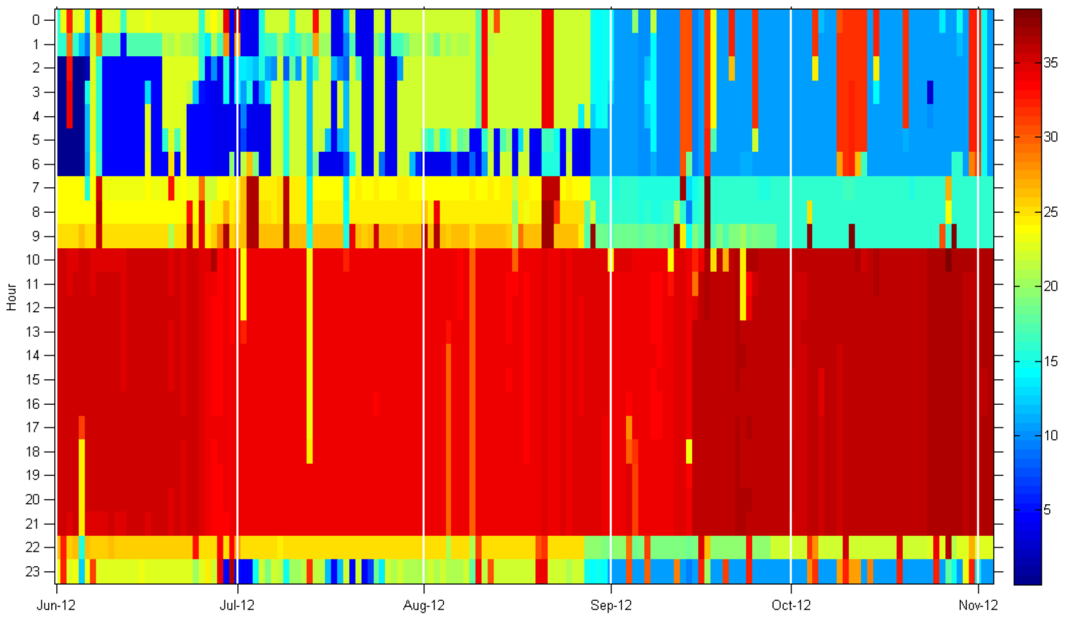

Figure 3: Lighting electric consumption of building G (kWh)

On the other hand some system shows high base loads during nights, as seen in Figure 4.

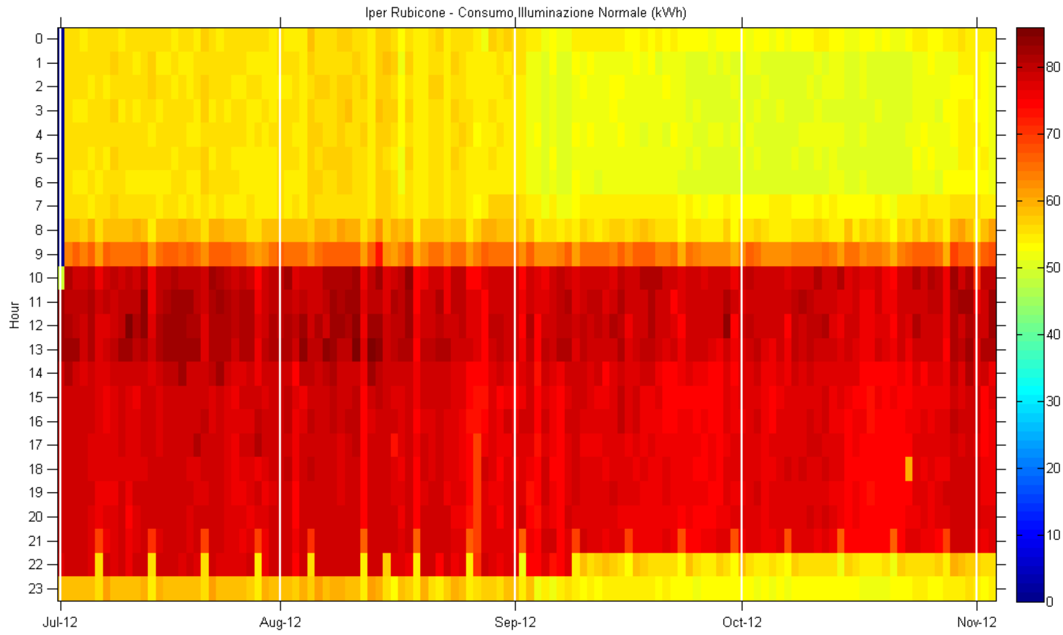

Figure 4: Lighting electric consumption of building E (kWh)

Measuring energy saving from cabinet glass covering

Hourly data permit to verify potential energy efficiency measures for the specific activity. In some of the buildings analyzed the refrigerated cabinets were refitted with a glass covering. Refrigerated cabinets are a sensible task in retail chains: it is obvious that open cabinets are inefficient but marketing theory is still unwilling to impose any physical obstacle between potential customer and products. In the building analyzed the daily economic income was calculated before and after the glass covering, finding no explicit correlation between products sell and covered cabinet. Some test were also made to understand if the customers would close the cabinet: evidence showed that at the end of the day all the cabinet was closed without workers intervention.

The cabinet analyzed where covered with a double glazing system. The composition of the covering packet is 6mm glass (hot side) 10mm of air and 4mm glass (cold side) with low emissivity coating. The thermal transmission of the double glazed cover is 1.5 W/m^{2}K. Where the cabinet are connected to a centralized refrigeration system, the glass covering will not modify air conditioning consumption in summer. Stand-alone cabinet instead, impose a huge thermal load to the conditioned space; in this case covering them will diminish also air conditioning consumption. The energy saving related to this measure was about 22% on the fod refrigeration at 4°C system electric consumption, hourly data shown in Figure 5. It is clearly seen that at the end of August the cabinets were retrofitted.

Main findings from hourly analysis

The monitoring data and analysis shows the following results about the buildings considered:

- There is a relatively small variability in specific global electric consumption.
- There is a big variability in specific loads consumption (HVAC, food refrigeration, lighting).
- Lighting system is not well managed.
- Installing double glass on refrigerated cabinet has huge impact on electric consumption.

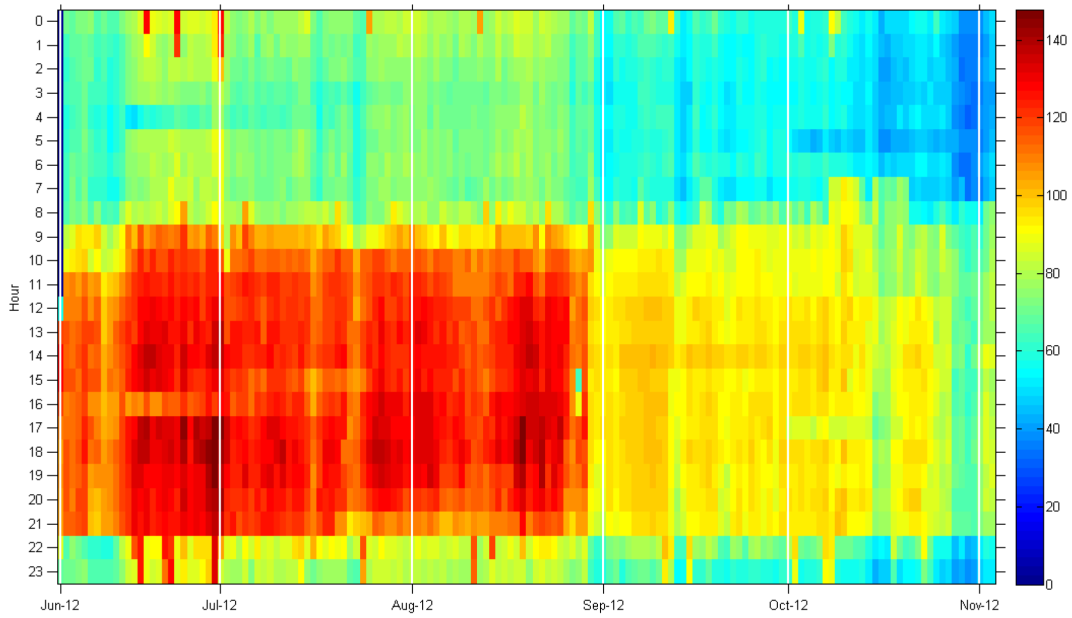

Figure 5: Food refrigeration (positive temperature) chiller consumption in building F (kWh)

Results of monthly benchmark analysis

This section will show monthly benchmark for HVAC system consumption, defined with three and four variables. The supermarket consumption compared is the A.

Focusing on benchmarking evaluation for HVAC consumption, a multi-linear regression was evaluated to describe the HVAC consumption in respect of:

1.	Gross internal area	GIA
2.	Climatic conditions (monthly mean temperature)	ExtT
3.	Working hours	Occ
4.	Internal loads	Loads

Two models were analyzed, one with just three input variables (GIA, ExtT, Occ) and one with four variables (GIA, ExtT, Occ, Loads). The variables were selected based on similar studies [2,3,4,5]. The measured internal loads represent an innovation in this field, since generally the consumption data are limited to total electric income [6]. The 3 variable model does not provide a good output, since the error between the regression output and the measured data is more than 20% (Figure 6). R^2 values is about 0.4.

The 4 variable model, instead, produces good correlation, R^2 values is about 0.8, with the result always below the 20% error (Figure 7). The model proposed work quite well since the buildings belong to the same Company, which has similar distribution of spaces and activities. Significant variability in load intensity was found in previous chapter; hence the model help to select the buildings that has anomalous consumption.

Definitely, HVAC consumption benchmarks without taking into account internal load metering are affected by a large prediction error.

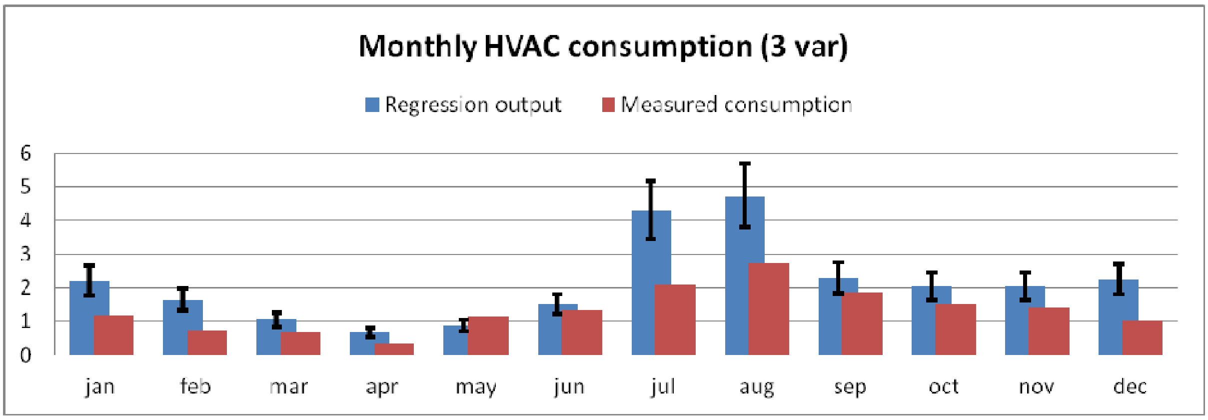

Figure 6: 3 variables model results (kWh/m^2)

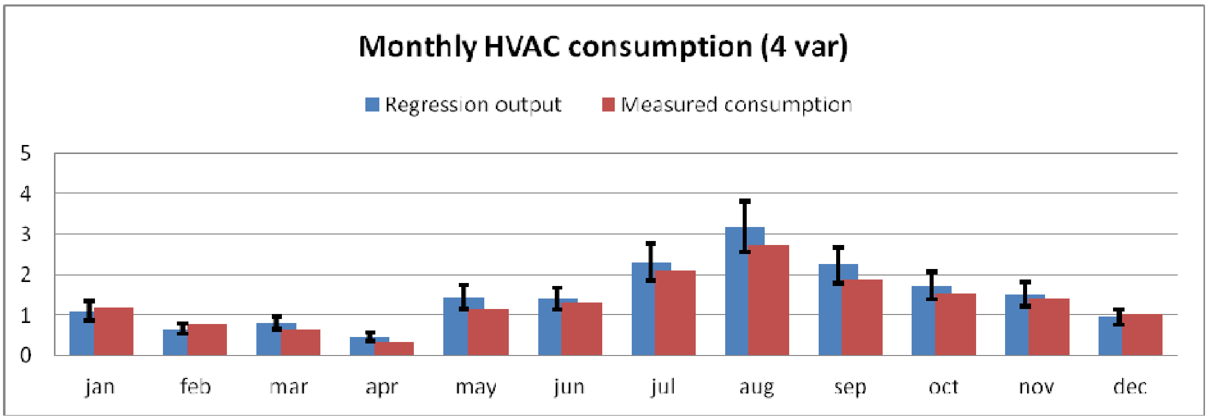

Figure 7: 4 variables model results (kWh/m2)

General Conclusions

Large-scale retail chain buildings have an impressive specific electric consumption. Since they are working 356 days per year, every efficiency measure that could be implemented will save high amounts of energy.
In addition to the first findings, shown by electrical hourly consumption, we can define a set of recommendation from the experience gained. Those recommendation, taken from the work on the total set of Italian buildings, are focused specifically on metering system installation and data availability.
The information on building and system varied sensibly. Also the reliability of metered data is depending on those factors:

- Presence of an Energy Manager;
- Age of the building and system;
- Presence of an ESCO managing the HVAC system.

An important help in energy metering should be the BMS, if properly designed and installed. BMS can effectively perform energy metering (provide energy metering functions are clearly indicated among the design specifications of some BMS). Our experience indicates, however, that adding such capability to an existing BMS implies sometimes high costs and technical problems that are difficult to overcome. The experience gained in using existing BMS for HVAC energy monitoring has yielded several hints which may eventually lead to a complete specification. The following is a non-exhaustive list of point to the designers and installers that need attention:

- Electric meter characteristics (type of data collected, accuracy, data storage) and number (e.g. separate chillers + cooling tower, pumps, AHU).
- Thermal energy meters: specifications for hot water and chilled water flow rate and temperature measurements.
- Environmental data measurements: indoor and outdoor air temperature and RH.

- Time coding: the data acquisition time interval should be specified by the user, typically in the range from 15 minutes up to 1 hr, depending on the type of data; the time sequence of collected data should never be interrupted, which means that, if for any reason the data are not collected at a given time, a conventional figure should be recorded. Daylight saving time should be managed in a non-ambiguous manner.
- Data format: the correspondence between data and physical quantities should be clearly specified with alphanumeric codes that make the identification easy to the inspector.

Data showed that HVAC improvements are possible, but for those activities also lighting and food refrigeration need measures of energy efficiency. Building simple models to compare an average consumption with the actual one is possible, but internal load consumption data are necessary.

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"Solar and light input to the transparent façade of the building; the benefits of dynamic solar shading systems."

Anders Hall, ES-SO, European-Solar Shading Organization

"Energy consumption for cooling is expected to increase sharply by 2050 – by almost 150% globally, and by 300% to 600% in developing countries" says the International Energy Agency in a recent publication (Technology Roadmap Energy Efficient Building Envelopes, December 2013) and it concludes, among other 'key findings and actions', that "*new office buildings should be fitted with integrated façade systems that optimize daylight while minimizing energy requirements for heating, cooling, artificial lighting and peak electricity use. Exterior shading, proper orientation and dynamic solar control should become standard features globally in new buildings and can also be applied to existing buildings; in new buildings, window-to-wall ratios can also be optimized. Pilot projects have demonstrated that such systems can enable energy savings of up to 60% for lighting, 20% for cooling and 26% for peak electricity".*

2005: ES-SO's ESCORP EU 25 study

As early as 2005 ES-SO, the European Solar Shading Organization, commissioned a scientific study *'Energy Saving and CO_2 Reduction Potential from Solar Shading Systems and Shutters in the EU25', i*n short ESCORP-EU 25. This study, available from www.es-so.eu shows that the feasible energy savings and carbon emission reduction from solar shading are very significant and represent an important part of the targets set by the European Commission. Expressed in million tons of CO_2 saved, the study shows a potential of 111 Mt/a for the (then) EU25, with 31 Mt/a from reduced heating demand in winter time (i.e. use of renewables), and 80 Mt/a from lower cooling loads. The potential reduction of energy demand is 43 MToe/a, almost ten percent of the energy consumption in the building sector. An ISO validated building simulation program was used on the basis of ambitious but realistic assumptions. But how do simulated calculations compare with real life measurements? In a case study, we will try to lift a veil.

2014: The EU policy context

The EU Climate and Energy Package commits Europe to transform itself into a highly efficient, competitive, low-carbon economy and presents an integrated approach to climate and energy policy which seeks to combat climate change, increase energy security and strengthen competitiveness.

Buildings, responsible for almost 40% of total energy end-use, offer the most promising potential for energy efficiency and energy savings in both refurbishment and new build in all parts of Europe. The Energy Performance of Buildings Directive (EPBD) is central to realizing this potential. The EPBD-recast adopted in2010 requires that from the year 2020 onwards all new buildings will have to be 'nearly-zero energy buildings' (nZEB), comply with high energy-performance standards and supply a significant share of their energy requirements from renewable sources.

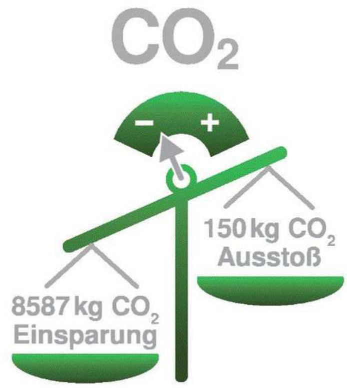
Fenestration plays a key role in optimizing building envelope performance, enabling control of solar gain and sustaining occupant comfort. Solar shading is a technology which permits dynamic control and can be successfully employed in a high performance building as an individual measure or as a component of a package of energy efficient measures. The energy saving and CO_2 reduction potential of solar shading in European buildings is very significant. Effective use of solar shading can contribute to the reduction of overheating and air conditioning use, improved thermal insulation of fenestration and hence lower space heating loads. In addition, solar shading can promote improved thermal and visual comfort for building occupants.

Solar shading will play a key role in the challenge to implement integrated and adaptable building envelopes. Automated blinds and movable sun barriers integrated in advanced building control systems for control of the active building envelope will successfully combat excess solar gain and prevent overheating and occupant discomfort in high performance buildings.

Effective use and implementation require intelligent selection criteria and reliable means to determine energy performance. The recent development of a family of related European Standards enables the calculation of energy performance of complex glazing systems in reliable and comparable ways which assist the integration of energy efficient solar shading from the design stage of the building.

Let's be specific: CO_2 Footprint of a Venetian Blind

Boiled down to its essence, we can state that solar shading reduces the need for artificial cooling because it reduces solar heat gain into a building. As stated above, it does more than that: it enhances indoor comfort, thereby creating better conditions for productive work. If properly automated, it will allow better use of free, natural daylight. It will even add an extra layer of insulation to the windows in winter time, reducing the need for heating. All of that means saving energy and helping reduce the emission of carbon dioxide, a major greenhouse gas. And that is a contribution to sustainability. An example will show this.



A recent study at the Institute of Applied Logistics (IAL) of the University of Applied Sciences in Würzburg-Schweinfurt was undertaken by a member of ES-SO, to calculate the CO_2 footprint for venetian blinds. This particular sun protection device is popular in central Europe mainly because of its flexibility in controlling the energy and entry of light depending on the day and the season. The CO_2 footprint was calculated according to the Greenhouse Gas Protocol, the most widely used international accounting tool for quantifying and managing greenhouse gas emissions. The results are surprising: a venetian blind will save around 8.500 kg of CO2 over its life cycle – and yet creates only 150 kg of CO2 from production to disposal."

For the calculation a typical motorized external venetian blind with 80mm slats was chosen with dimensions 1.20m x 2.00m. The manufacture of such a blind results in CO_2 production and the calculations showed that, assuming a life span of 20 years, a venetian blind in the course of its product life creates around 150 kilograms of CO_2 emissions. However, this blind will save over 8.500 kg of CO_2, so that is a 57-fold improvement. The result of this study demonstrates the enormous energy saving potential of external shading.

If this study demonstrates the impressive energy saving potential and reduction of carbon footprint of an aluminium external blind, it follows logically that other types of external shading, in particular the external roller blinds with various types of sun shading fabric, will even have a better energy saving and carbon footprint record, as they usually generate much less CO2 in their production process.

Manual or automated solar shading?

The only real solar shading is one which is dynamic and fully automated, often with the addition of local over-ride. This has been proven in numerous research projects all over the world. But still, the use of manually controlled shading is the solution frequently being chosen, mainly because of cost and the fact that solar shading still is considered to be an "addition" to the building and not the obligatory part of the total construction it ought to be. There have been many discussions on how to calculate the energy control and daylight harvesting from manually controlled shades. Some countries recommend assuming the blind to be operative 50% of the time, for calculation purposes.

Is that so? An ongoing project in Switzerland run by ESTIA SA in Lausanne shows interesting information on this subject. ESTIA SA's Prof Bernard Paule (Chargé de cours at Ecole Polytechnique Fédérale de Lausanne) is making a live study of a three façade (East, South, West) building counting the actual movements of manually controlled outside blinds. The aim is to establish valid information about the actual use of manually operated blinds. They started by making a preliminary study in 2003-2004 and the result was that the blinds were moved, on average, a bit more than 12 times per year, that is only once per month! (Illustration from ESTIA SA)

This definitely supports the statement that solar shading has to be automated to bring the positive effects we are looking for. It also tells us that many of the calculations being made today on both natural light and energy by HVAC consultants, engineers and architects are often wrong, as the positive effects of manual shades are grossly overestimated.

It is therefore better to talk about 'solar control' or 'solar management', rather than 'solar shading'. This wording shows the dynamic character of the technique that is now state-of-the-art. Intelligent controls for a smart combination of internal and external shading have the best results. The external blinds to minimize the solar gains and cooling load, the internal solar shading to avoid glare and minimize the heating needs during cold nights and reduce electricity use for artificial light. Real solar management is an essential building technology for low energy buildings that will help reach the 80% energy savings in buildings the European Commission has targeted.

A Best Practice Project in Gothenburg, Sweden – Bengt Dahlgren AB

By sharing the experiences and results from this project we hope to inspire you to promote similar initiatives in your local market.

In 2008 it was decided to try and build the most energy efficient office building in Sweden meeting the criteria of the Green Building Council. A non-profit organization, the Sweden Green Building Council works to influence and develop the environmental and sustainability programmes in the building industry. For this project, the target was to design for an energy end-use of not more than 75% of the limit of 100 kWh/m^2.a that the Swedish government required for a building permit, and that figure was to cover the total energy consumption, the business consumption included. Today the limit has already been brought down to 90 kWh/m^{2}a.

The first and important step was to define the objectives. The project was based on values like:

- o Holistic view
- o Involvement of all key parties

- o Excellence/knowledge amongst parties
- o Innovative thinking using proven technology

Very early it was also decided that 100% demand control was to be used for

- o Ventilation
- o Indoor temperature
- o Light
- o 50% of wall sockets for appliances

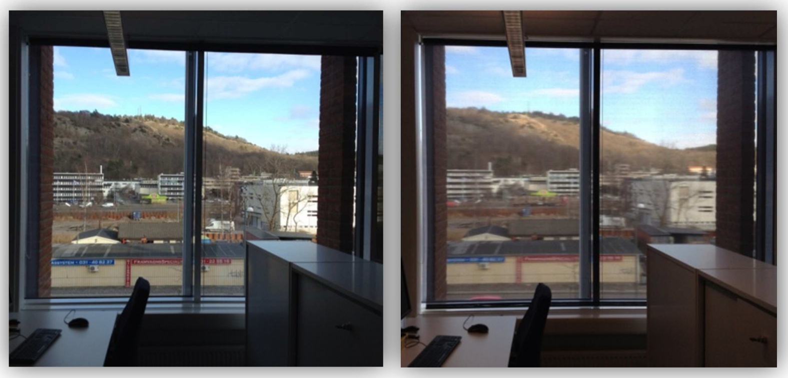
Meaning e.g. that the ventilation would only run at full effect when people are present in the room. Empty rooms would only be ventilated at 10% effect. Then the indoor temperature would be allowed to fluctuate +/- 2,5˚C, from the set point of 22,5˚C at presence but +/-4.5˚C when empty. A heat exchanger was mounted in front of the ventilation outlet on the roof giving an extra 2˚C in energy to re-use a large part of the year, energy otherwise just wasted.

Emphasis was put on the construction of the building envelope and it should include dynamic solar shading. The choice was for outside Venetian blinds. The City Architect wanted 65% of glazing to meet the design criteria for the surrounding area. The average U value for the façade was set to 0,40W/m^{2}K, split as follows:

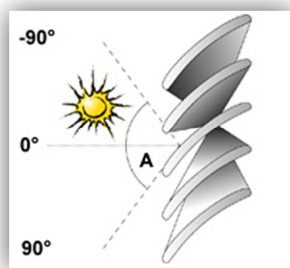
- o Glass < 0,70 W/m^{2}K
- o Window < 0,85 W/m^{2}K (triple/Argon)
- o Wall 0,20 W/m^{2}K

A system was installed to keep the indoor light at as stable a level as possible and to compensate for the changes on the façade – to adjust to whether the solar shading was active or not. The manual override of the light requires action of the people to turn it on, while when a room is empty the lights are turned off automatically, after a set delay time. Today the conclusion in the building is that the lights are mostly off!

Interior blinds (roller blinds, or 'screens') were installed to take care of any glare problems. The fabric chosen was of a mid grey colour as this gives a good view to the outside. (See illustration).



Inside screen UP (left)
inside screen DOWN (right)



The outside blinds are controlled with a "suntracking" function meaning the slat angle follows the variable azimuth of the sun during the year, keeping the blinds as open as possible for the outside view.

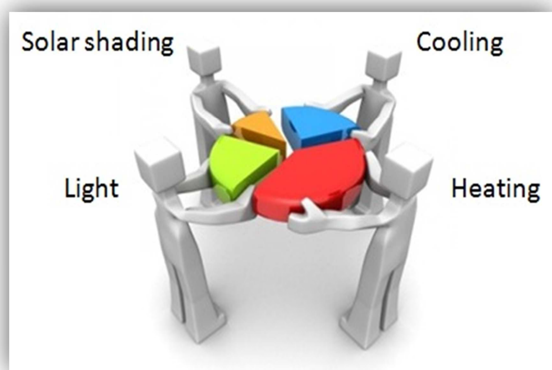
The blinds' physical construction is highly resistant to wind, insuring that only very few hours are lost by the coincidence of strong are shaped in a special profile resulting in stability and a more direct cut-off of the solar

wind and sun. The slats two important features: radiation.

The animeo IB+ system controlling the operation of the outside blinds is set for Down/Closed position during cold nights, seven days a week, holding the heat inside the building. During cold days, when the building is empty, such as on Saturdays and Sundays, it is set for Up/Open, letting the sun in whenever possible and picking up the solar heat gain. In both cases, good use is made of the U-value of the window. The choice was made to have no local switches to override the central commands, so the system is always on fully automatic for optimum efficiency. This is unusual as very often in commercial offices, to satisfy the users, manual overrides are available to change the settings to the personal taste. Here, the internal roller blinds in screen fabric were installed, as indicated above, to complement the function of the outside blinds and allow good automatic operation to take care of heat and light problems.

A total of 26 different meters were then installed to measure the actual, specific use of electricity for both the operation of the building and the consumption of electricity for business purposes. In 2012 the total consumption, including the part for the business machines, was measured to be 79 kWh/m^2. With some further optimization of the different systems in the building the goal (not more than 75 kWh/m^{2}a) was reached and late 2013 the building was awarded the Green Build Gold rating.

The key to success here can be summarized as follows:



- Relatively low tech, off the shelf products were used, but in a good combination
- Solar shading brought significantly larger savings than calculated in the pre-studies.
- Demand and Presence Control is key to the success
- To early involve -- and cooperate with -- all key consultants and suppliers is crucial
- To instruct all the occupants about how the building works is important, to make them understand why certain things happen, why systems go automatically ‘on’ and ‘off ‘, so they become ‘part owners’ of the total solution and act accordingly.
- This solution can easily be copied to other both new and existing buildings. No need for advanced innovations at high costs.

A full presentation on the project can be downloaded from www.es-so.eu. It is the presentation given by ES-SO at the REHVA CLIMA 2013 Convention in Prague.

CONCLUSION

In order to meet the requirements on energy efficiency and healthy indoor climate it is obvious we need to start acting in a new way to be successful. The Best Practice project from Gothenburg is proof that this can succeed. It does not have to be difficult and complicated. In many cases there are already a lot of solutions available that can be used in a smart way and with excellent results. But it will not be easy as it takes a change of conventions and new systems to handle the projects.

The combination of different techniques is what brings the final result. We need to meet early in the process and respect the fact that others will contribute as well. It has to penetrate the whole chain of events from the Owner, Architect, Consultant, Builder, Supplier to the End user. In a clear sense the

implementation of the different systems like Green Build, BREEAM and LEEDS is helping to drive this development in a positive way.
At ES-SO we also hope that this Paper has helped to convince you of the importance to combine dynamic solutions for both light and shadings, for the benefit of both society and the people in it.

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Improving the building envelope by using cool materials as a passive cooling technique

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Abstract

This paper presents the use of cool materials as a passive cooling technique that improves the building envelope and leads to cooling energy savings and improved indoor thermal comfort conditions. An overview of cool roofs technology will be presented and special focus will be given on the application of cool materials on commercial buildings. Results of energy savings and indoor thermal comfort conditions improvement from the application of cool materials on commercial buildings in Europe and worldwide will be compiled. In addition recent developments regarding cool roof related policies, standards and product certification will be analysed. The activities of the European Cool Roofs Council (ECRC), a non-profit association aiming at developing scientific knowledge and research in relation to “cool roof" technology and promoting the use of cool roof products and materials in Europe will be presented. The ECRC has given an important boost in the cool roofs technology and market in Europe and one of its core objectives is the development of a Product Rating Programme, a uniform and credible system for rating and reporting the radiative properties of roofing materials, mainly solar reflectance and infrared emittance. The main aspects of this program will be reported.

Keywords: cool roofs, passive cooling, energy savings, product certification

1. Introduction

The technology of cool materials has gained a lot of interest the past few years in an effort to mitigate the effects of the urban heat island phenomenon and increase the energy efficiency of buildings by reducing their cooling energy demand. Cool materials are characterized by high solar reflectance (SR) (ability to reflect solar radiation, reducing heat transfer to the building) and high infrared emittance (e) (i.e. faster release of absorbed heat in the form of infrared radiation). These two properties result in affecting the temperature of a surface. If a surface with high solar reflectance and infrared emittance is exposed to solar radiation it will have a lower surface temperature compared to a similar surface with lower SR and e values [1,2]. If the cool surface is on the building envelope, this would result in decreasing the heat penetrating into the building and for a surface in the urban environment this would contribute to decrease the temperature of the ambient air as the heat convection from a cooler surface is lower.

A large number of experimental and modeling studies [3-11] demonstrate the benefits of cool materials applied to building roofs that can be summarized below:

- Reduction of building heat-gain: the temperature of a cool reflective roof typically increases only a few degrees Celsius above ambient temperature during the day.
- Savings on summertime air conditioning expenditures, in conditioned buildings ranging averagely 10–40% depending on building characteristics and use, climatic conditions.
- Improvement of thermal comfort conditions in non AC buildings.
- Reduction of peak electricity demand (resulting in downsizing of equipment, reduction of likelihood of power failures on extremely hot days, financial savings for electricity customers who are charged for the largest amount of power (watts) they demand during a billing period).
- Enhancing the life expectancy of the roof system reducing expenses for maintenance (because of less UV degradation and less thermal fatigue).

- Mitigation of the heat island effect by 1–2 ◦C, as less heat is transferred to the surrounding air.
- Reduction of air pollution and CO_2 emissions.

Although research regarding the application of cool materials on building facades is far less advanced compared to the cool roofs research, due to the complexity of vertical applications, results indicate that the benefits from such applications can be important for hot climatic conditions. The use of cool coatings on façades can contribute to reduce the energy consumption of high multi-stories buildings in regions where cooling needs are predominant over heating energy requirements [12,13]. Petrie et al.(2007) [14], showed that the application of IR reflecting coating on a ranch house results in annual cooling energy savings between 4% and 13%. Doya et al., (2012) [15], used a reduced-scale of 4 street canyon rows to test the impact of using cool colored coatings on facades of buildings in an urban setting. They found that after application of cool selective paint on street facades, reductions of surface temperatures up to 1.5 ◦C were observed compared to the reference street. Direct impacts on indoor air temperatures were also measured (indoor air temperature difference increased up to 2.5 ◦C).

A wide range of cool materials is commercially available. Most cool roof solutions are based on the use of white or light colored materials. However, in an effort to respond to the need for darker colors on building steep slope roofs and facades that are visible from the street level, and therefore subject to the aesthetic preferences of the users or regulations regarding their exterior appearance (e.g. in historical centers) or the need for reduced glare, a range of cool colored material have been developed. A cool colored surface is a spectrally selective surface that presents high absorbance in the visible range (400-700nm) and high reflectance in the NIR range (700- 2500nm) [16, 17, 18, 19]. It is also characterized by high emissivity. Some of these developed solutions have already been implemented into commercial products that can be found in the Cool Roof Rating Council (CRRC) and European Cool Roofs Council (ECRC) rated databases [20,21].

The research for development of new cool materials with advanced properties for the building envelope is ongoing and includes the development of cool-photocatalytic materials that have self cleaning properties, advanced cool materials that have stronger resistance to ageing, thermochromic materials that change their optical properties with temperature, and the development of other types of cool material with advanced properties [22, 23, 24].

In the next sections the potential of cool roofing material to reduce energy consumption in non residential building is analyzed and an overview of policy issues related to cool materials within a European context is described. Finally, the role and objectives of the European Cool Roofs Council is reported as well as the main aspects of the European Cool Roof rating program under development.

2. Assessment of the potential of cool roofs to reduce energy consumption in non residential buildings

A large number of experimental and modeling studies have been performed in non-residential buildings documenting cooling energy savings from the application of cool roofs. More specifically, Akbari et al., [25] have monitored the effects of cool roofs on energy use in six California buildings: a retail store in Sacramento; an elementary school in San Marcos and a four-building cold storage facility in Reedley. They found that the savings in average daily air conditioning energy use was about 72 Wh/m2/day (52%), 42–48 Wh/m2/day (17–18%) and 57–81 Wh/m2/day (3–4%) for each building type respectively. Akbari [26] documented energy savings of 31–39 Wh/m2/day in two small commercial buildings with very high internal loads. Konopacki and Akbari [27] measured energy savings of 12% in a large retail store in Austin, Texas. Konopacki et al. [28] report measured energy savings of 12–18% in two commercial buildings in California. Hildebrandt et al. [29] report daily energy savings of 17, 26 and 39% in an office, a museum, and a hospice, after the application of cool roof in Sacramento. Akridge [30] reported energy savings of 28% for a school building in Georgia. Akbari et al. [31] have measured cooling-energy savings of 46% and peak power savings of 20% achieved by increasing the roof reflectance of two identical model classrooms in Sacramento. Parker et al. [32]

measured seven retail stores in a Florida mall before and after applying a cool roof coating and measured a 25% decrease in summer cooling energy use. Boutwell and Salinas [33] showed an office building in southern Mississippi saved 22% after the application of a cool roof coating.

The previous studies indicate significant cooling energy savings arising from the application of cool materials on commercial buildings' envelope. However, these studies have mainly been conducted in the U.S., in locations representing generally hot climatic conditions. Very few studies aiming to quantify the impact of cool materials on non residential buildings have been carried out in Europe where the climatic conditions include Mediterranean and also temperate conditions. An effort has been made to summarize such studies conducted in European locations.

In the literature five cases were found reporting the impact of the application of cool roofs on non residential buildings. All of these buildings have been monitored to demonstrate cool roof potential in terms of improving the thermal conditions in non-air conditioned buildings and reducing the energy consumption in air conditioned buildings. These buildings are: (a) a school building in Athens, Greece [34], (b) a laboratory building in Crete, Greece [35], (c) a public building in Trapani, Italy [36], (d) an office building in London, United Kingdom [37] and an industrial building in Oss, in the Netherlands [38]. The buildings were monitored, in regard to their energy performance and indoor environment, before and after the implementation of a cool roof technology. The monitoring results were analyzed and used as input for numerical analysis. A calibration analysis was performed by comparison of the calculated versus measured indoor air temperatures, in order to have a model as close as possible to the real indoor and outdoor conditions. Once the models were fine tuned, it was possible to compare the performance of the building after and before the cool roof application for a whole year. Table 1 summarizes the basic information regarding the five buildings as well as the load savings and indoor temperature reduction. The increase in solar reflectance ranges between 0.37 -0.69. For the two temperate climates (London and Oss), the increase in solar reflectance was lower and the roof insulation was higher, suggesting a less significant impact from the cool roof. Cooling load savings range between 17.4-73% while heating load increase ranges between 5-43% suggesting that the application of cool materials can be beneficial even for temperate climates. In terms of thermal comfort during summer, temperatures reductions are in the range of 2°C suggesting improved conditions for non AC buildings.

Table 1. Comparison of the savings and temperature reduction from the application of cool coatings

Location	**Building Type**	**ΔSR**	**Roof area (m^2)**	**Roof U-value ($W/m^2/K$)**	**Cooling load savings (KWh/m^2 / %)**	**Heating load increase (KWh/m^2 / %)**	**Indoor T reduction (°C)**
Athens, GR	School	0.69	410	1.97	3/40	2.6/10	1.8
Iraklion, GR	Laboratory	0.69	25	0.985	20.6 / 27	3.8 / 43	1.5
Trapani, IT	Office-Lab	0.61	706	1.26	6.1/ 54	NA	2.3
London, UK	Office	0.5	97.6	0.6	4.4/17.4	2.5/13.9	2
Oss, NL	Industrial	0.37	1685	0.591	7.1/ 73	7/5	5

It should be pointed out that the overall energy demand for cooling and heating has decreased for all the buildings after the application of a cool roof solution, even for the two buildings located in temperate climatic conditions. However, estimating energy savings depends on a set of parameters related to the building construction and operation characteristics.

3. Cool materials policies, programs and initiatives in Europe

Cool roofs technology has long been applied in the U.S. where there are measurement standards related to cool roofs, it is a part of the energy code in many states, and organizations like the U.S. EPA Energy Star, the U.S. Cool Roof Rating Council, programs (e.g. LEED) and incentives are promoting it. Cool roofs technology is also applied and promoted in other countries around the world like Japan, Australia, Brazil, India etc. In Europe, the foundation of the European Cool Roofs Council (ECRC) has given an important boost in the cool roofs technology and market. The ECRC is a non-profit association aiming at developing scientific knowledge and research in relation to "cool roof" technology and promoting the use of cool roof products and materials in Europe, including developing a product rating programme for such products and materials. The foundation of the ECRC was supported by the IEE Project "Cool Roofs" (IEE/07/475/SI2.499428). Its initiatives are driven and paid for by its members through an annual membership fee. It is a voluntary organization that brings value by promoting the benefits of cool roofing products to regulators, policy makers, consumers and other stakeholders. The ECRC was established in 2011 organization engaged in the following activities:

- Research and study of 'cool roof' technology.
- Production of information material relevant to 'cool roof' technology.
- Support to bodies, organizations, governments, the European Union on particular issues relevant to the 'cool roof' technology and policy.
- Education of members, teachers, students, legislators and the general public on 'cool roof' technology issues.
- Networking, connection and association with relevant organizations in and outside the European Union.
- Development of product rating standards concerning thermal and optical characteristics of roofing products.

The important participation and support from the European industry to the ECRC (since its establishment in 2011 more than 23 organisations have joined) underlines the great interest in cool roof technology.

Cool roofs represent a valid solution for European energy and environment policy challenges and represent good value for investment and the work performed in the framework of the Cool Roofs project and the ECRC has significant results in accelerating the penetration of cool roofs in the European market and also at policy level by the adoption of relevant standards and programs at national level. More specifically, four countries (Greece, UK, Germany, and Italy) have adopted initiatives to promote cool materials and Greece has adopted cool roof standards. In detail, in a Greek directive on "Measures to improve the energy performance and energy savings in public buildings" the use of cool coatings is suggested. In addition in the new Greek energy code the basic parameters of cool materials (solar reflectance and infrared emittance) are taken into consideration and should be defined for the estimation of the energy performance of buildings. Italy is in the process of finalizing a national decree that will promote cool materials: it is a part of EPBD that focuses on regulating the cooling issues of buildings: residential, public and industrial. It is expected to redraw the methodology to assess the energy performance of buildings, to include minimum requirements and will include cool roofs and cool walls as energy efficient technologies whose benefits are obliged to be verified in case of new buildings or renovation. In the UK, BREEAM Communities is a voluntary certification standard that includes cool materials as a heat island mitigation strategy. The German Sustainable Building Certificate [39], which is effectively a standard of the German Sustainable Building Council, on the topic of ecological quality includes the Criterion 9: Microclimate, that specifies that the choice of appropriate materials can contribute to the heat island mitigation and requires the documentation of the albedo values of roofs and facades.

In addition the MAIN Project: MATÉRIAUX INTELLIGENTS [40], which is co-financed by the MED Programme of the European Union, aims at promoting knowledge, use and trade of "cool" products, which positively influence people's health and the environment, mainly in southern Europe. The MAIN Project takes place within every type of territory in Southern Europe (seaside, countryside, and also some mountain area), targeting a wide range of stakeholders: families, building firms and artisans, technicians, material manufacturers, policy makers. It is the tool to promote a cooler generation of buildings and cities. This is set up by means of platforms, the Territorial Islands, implementing at local level the actions developed by the partners to disseminate cool materials and facilitate their access and proper use. Each Territorial Island will implement at least one case study using cool materials and measure their performance. One of the main outcomes of this project is the development of a "MAIN label" issued according to criteria based on the international state of the art. Product performance is rated according to test methods specified by the European Cool Roof Council. In the framework of the project In the framework of this project short courses and other educational tools are designed and delivered at two different levels: for designers, and for other stakeholders of the building sector (technicians of building firms and artisans, public officers and policy makers, product manufacturers), in order to promote access and proper use of "cool" products. A company/ project that receives the MAIN label must have simultaneously rated products, informed technicians and trained designers.

4. The European Cool roof product rating program

One of the core objectives of the ECRC is the development of a Product Rating Programme, in which roofing product manufacturers will be able to label various roof products with radiative property values rated under a strict programme administered by the ECRC. Code bodies, architects, building owners and specifiers can have credible radiative properties data provided by the ECRC Product Rated Programme. The radiative properties that will be reported by this product rating program are the solar reflectance and the infrared emittance. The Solar Reflectance Index of the products will also be reported. In the framework of this program, products will also be rated for ageing by being exposed to outdoor weather conditions for a period of three years in European weathering test sites. Manufacturers and Sellers have the opportunity to label roofing products with the measured values of their Initial and aged Radiative Properties. These properties are determined and verified through testing by accredited/approved test laboratories and a process of random testing of rated products. Any roofing product can be tested as long as it is in compliance with the specifications and requirements defined by the ECRC. The initial and aged radiative properties of the ECRC rated products will be displayed in the ECRC rated products database and also on a specific label on the product. It should be pointed out that the ECRC product rating program does not specify minimum or target values for any radiative property.

5. Conclusions

Cool roofs contribute to mitigating climate change, reduce the urban heat island effect & increase the sustainability of buildings. Analyzing the data found in the literature from five case studies representing non residential buildings which are located in different European cities it was concluded that applying cool roof technology in non residential buildings in Mediterranean and moderate climatic conditions could be beneficial in terms of increased thermal comfort in the summer and could decrease overall energy use for heating and cooling. However, energy savings depend on building related construction and operation characteristics. The cool roof concept and products are on the move both internationally but also in Europe as they present part of the solution for EU energy & environment policy challenges. The ECRC product rating program will provide a uniform and credible system for rating and reporting the radiative properties of roofing materials. In addition by engaging with policy/decision makers as well as major stakeholders the ECRC plans to increase cool roof awareness, promote the benefits and facilitate incentivising of cool roofs.

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A review study of Decentralized Power Generation Potential of the Indian building sector

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Abstract

One of the major barriers to the sustainable growth of India is the energy crisis. Despite of continuous efforts and investment of Government in the energy sector, in 2011, 300 million of Indian population was deprived of electricity. The segment of population which has access to electricity faces the problem of intermittent and unreliable power supply. This is because India faces transmission losses of more than 32% (in 2010) as compared to global average of 15% because of inefficient transmission network and location of power generation sites at very far distances from the end use sites. Also, the rapidly growing building sector is responsible for at least 30-40% of energy usage and this demand is growing annually at 11-12%, which is almost twice global average of 5-6%.These are serious matters of concern for India and calls for a viable solution [1].

One of the most promising solutions to this situation is energy efficient buildings (EEBs) with grid-connected on-site energy generation using renewable energy sources i.e. Decentralized energy generation (DE). Various building components suit as power generation sites through more than one renewable energy sources. With buildings growing in India at very high rate, and India being rich in renewable energy sources, this is the most viable option for mitigating energy crisis.

The environmental, social and economic benefits of EEBs with grid connected DE include but are not limited to reduction in carbon emission around 30-40% which is caused due the present coal-based energy generation system, economical since the cost of setting up grid connected DE will clearly be less than setting up high-voltage transmission networks. Also, due to grid connected DE, the surplus energy producers will receive Feed-in tariff which can in turn decrease the pay-back period and also will not isolate them from grid supply. It will develop a feeling of unconventionality and social responsibility in the community and will lead to an attitude change towards energy usage thus reducing carbon footprints. It will be a revolution for people deprived of basic energy services.

The presented work identifies barriers to the proposed model in India. It reviews EEB standards followed in different countries, administrative policies and reforms implemented, financial mechanisms, incentives and feed-in tariff offered and the technical and environmental consequences of the model. As an outcome of the study, the paper proposes a way forward to successfully implement EEB grid connected DE in India.

1. Introduction

The energy demand of India, as witnessed in 2009, was the third largest in the world after China and United States. It has increased more than twice from 319 million tonne of oil equivalent in 1990 to 669 million tonne of oil equivalent in 2009. Nevertheless, the per capita energy consumption has risen at a low pace from 268.13 kWh in 1990 to 589.94 kWh in 2009 [2]. Thus it can be inferred that the per capita energy increase has a long way to go. To satisfy this demand, India needs a powerful and self-dependent energy sector. Unfortunately, the present energy resources are unable to meet the existing demand. In the year 2010-11, base load requirement was 861,591 million units against the availability of 788,355 million units, a discrepancy of 8.5%. The peak demand was 122 GW against the availability of 110 GW, a discrepancy of 9.8% [3]. Also energy is generated far from cities and therefore two-thirds of primary energy inputs get wasted in transmission and distribution and thus adds up to the delinquent situation. In 2010, India faced T&D losses of more than 32% as compared to global average of 15%. For the energy generation to meet the energy demand at the same T&D losses, India needs to add about 135 GW of power generation capacity before 2017 which would require a capital investment of US$ 135 billion.

If seen from climate change point of view, Coal-based power plants account for over 60 per cent of the total carbon emissions in India. The country's power plants emit over 540 million tonnes of CO_2

annually. CO_2 emissions due to electricity production increased by 81.95% in the period of 2000-10 while the electricity production increased by 41.55% in the same period (World Bank Data). Thus the CO_2 due to electricity production have almost doubled in the period and points towards the inefficiency of the power plants to address the climate change issue.

In the previous decade, the infrastructure sector in India has developed at a rapid pace. Particularly construction industry is growing at the rate 9% against the world average of 5.5%, annually. Buildings are major consumer of electricity used for various domestic and commercial purposes. In India, they are responsible for at least 30-40% of energy use and this share is growing annually at 11-12%, which is almost twice the average electricity growth in the economy which is 5-6% annually [1]. According to GRIHA manual, there is an increased demand of about 5.4 billion units of electricity annually for meeting end-use energy requirements for residential and commercial buildings. In a typical building, approximately 80-90% of the energy is consumed for heating, cooling, lightning and other appliances. The other 10-20% is utilized during construction and material manufacturing. In 2010-11, domestic household consumption accounted for 28% of total electricity consumption [4]. It is estimated that two-thirds of the buildings that will be forming a part of the commercial and high-rise real estate in 2030 is yet to come up. Also, new buildings are coming up at higher pace while the old buildings are not replaced at the same rate. Thus, the rate of increase in energy is always cumulative. Therefore, buildings remain as major energy consumer for the present and next decade.

In India, buildings are built using conventional construction material and the use of recycled or reused materials is still for demonstration purpose only. Due to embodied carbon in the construction material and due to electricity usage, buildings also remain as potential CO_2 emitter. Globally, the urban areas contribute 70% while the housing construction and estate development contribute 40% to the GHG emissions. Buildings contribute approximately 50% of the world's air pollution, 42% of GHG emissions, 50% of water pollution, 48% of solid waste and 50% of CFCs (chlorofluorocarbons) to the environment [4].

Since the construction sector in India still emphasises on conventional less energy efficient buildings, it becomes difficult for the energy sector alone to compete with the increasing electricity demand. This calls for energy efficient buildings which consume less electricity than conventional buildings and also generate their own energy resources through renewable energy. Apart from this, EEB also present themselves as climate conscious buildings helping in reducing CO_2 and other Green House Gases (GHG) emission.

1. Power sector in India and a comparison with Germany, China and UK

1.1 Power sector in India

The power sector in India is the fifth in the world having an installed capacity of 223.625 GW (April 2013) [5]. The non-renewable energy fuels are leading energy producers constituting 87.55% against renewable energy sources sharing 12.45% [6]. Figure 1 shows the fuel-wise distribution of power sector in India, Germany, China and UK. It can be seen that Germany is currently the leading nation in promoting renewable energy (18%) among the four nations and has also significantly controlled the use of thermal energy sources. India and UK share second position in installing renewable sources. In renewable energy sources, China is leading the way in wind energy with 75,564 MW installed capacity by the end of 2012. Germany with 31,332 MW, India with 19,051 MW and UK with 8,445 MW installed capacity follows. In the case of solar energy in 2012, Germany is the leader with 32,509 MW peak power capacity. China, UK and India follow the order with peak power capacity of 8.043 MW, 1,831 MW and 1,686 MW respectively.

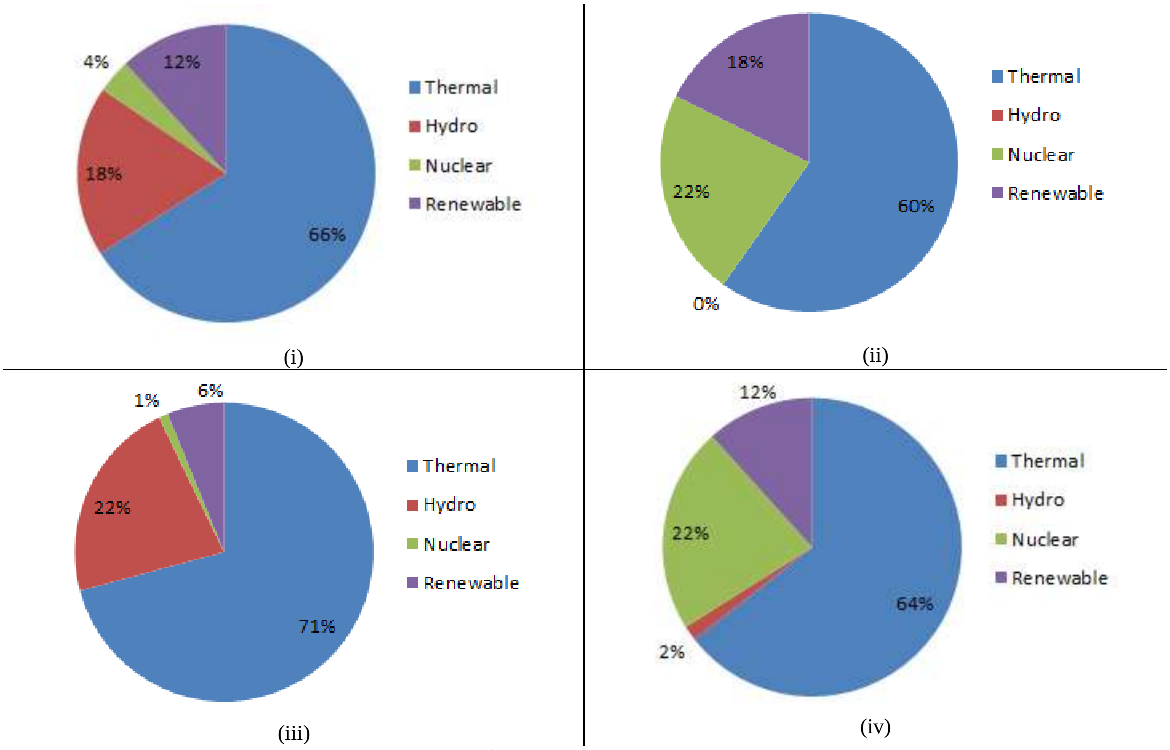

Fig. 1. Fuel-wise distribution of power sector in (i) India [3] (ii) Germany (iii) China (iv) UK

India's primary energy source is thermal sources including coal, oil and gas. The thermal sources account for 66% of the total energy sources. The most important matter of concern for the power sector is the shortage of coal to feed the thermal power plants. Despite of abundant coal resources, the nation is not able to meet the coal demand of the power plants. Reasons include conventional mining technology, coal theft and most of the coal reserves lying under protected forests or designated tribal lands. With cost of coal extraction rising and its potential to rise CO_2 emissions, it is a high time for India to move towards renewable sources. The average transmission and distribution losses are more than 32% yielding to inefficiency in energy distribution. More than 300 million people, in 2011, were deprived of access to energy which leads to the usage of traditional fuels including fuelwood, dung cakes for domestic needs. This is one of the reasons for high per capita CO_2 emission in India. Problems faced on the user side include long and frequent power cuts, voltage fluctuation and poor quality of power supply. This has led to increase in use of alternative diesel-based power generators which are prominent source of GHG emissions. Recent incident of July 2012 blackout has called for major reforms in power sector of India. Due to huge requirement of land and capital investment in setting up centralized power plants and the booming building sector paves the way for converting buildings into mini-power plants. [7] [8] [9]

2. Energy Efficient Building (EEB)

EEB encompass several areas, from efficient design and orientation to the technology used inside it to make the space heating or cooling more efficient. Efficient building concepts include passive solar design, use of efficient heating, ventilating and air conditioning (HVAC), use of solar water heaters, energy efficient lighting. EEB components include thermal envelope, renewable based construction material, components having higher insulation, efficient windows. EEB are designed to environmentally conscious and self-resource sufficient throughout its lifetime starting from laying of foundation to renovation and deconstruction. The objective kept in mind while designing EEB is to reduce the overall impact of the built environment on human health and natural surroundings. This objective is to be achieved by efficiently using energy, water and other resources; protecting and enhancing occupant health and improving employee productivity; reducing waste, pollution and environmental degradation. [10]

Moreover, it is in practice to generate the energy sources for the building using renewable energy sources over the building turning it in to net-zero building. Thus an EEB is a building unit with reduced energy demands through efficiency gains such that balance of energy needs can be supplied with renewable technology. A number of renewable technologies including PV, wind, biofuel and geothermal are available for power generation which are favourable over conventional energy sources such as fossil fuels and thermal energy sources. However they can be selected based on local availability, lifetime of the technology, technical and economic feasibility and potential to reduce environmental impact. [11]

2.1 Benefits of EEB [10]

The benefits of EEB are wide-ranging and multi-faceted which include:

2.1.1 Energy saving and energy security

Energy efficiency in buildings reduces the prevailing energy demand with maintaining the quality of service. This ensures in control over increase in demand and reduction in peak power demand which reduces the frequency and duration of power cuts. It also ensures availability of energy since the production is on-site and reduces dependency on conventional sources and their imports. Also on-site renewable energy generation provides better quality of power at reduced cost/kWh thus resulting in cost saving.

2.1.2 Cost savings, earnings and payback

Energy efficiency in buildings leads to lower energy bills and a positive return on investment. The benefits of EEB are long term and throughout the lifetime of the building. Also, the amount of surplus energy sent to grid produces revenue which adds up to the economic benefits. Early investment in EEB would be a more beneficial choice since the savings and earnings done in the early period can be invested in using advance technology. In this way, the economic benefits keep on accumulating.

2.1.3 Human health benefits

Intelligently designed EEB with health supportive technology has a positive impact on inhabitants leading to better productivity and better indoor environment. Also reduction in energy generation from thermal power plants reduces the pollution caused by them and thus improving local air quality.

2.1.4 Addresses climate change issue

Energy savings and on-site renewable energy generation result in reducing GHG emissions caused due to fossil fuel based energy generation. EEB also help in lowering the temperature due to use of efficient construction materials.

2.1.5 Green job opportunities

Up-scaling of EEB market will spur the market for advanced building technology and advanced construction creating green jobs. This will also be an added advantage for companies pioneering in EEB technology and green technologies.

3. Scenario of EEB in India

The growth and development of EEB in India is under the authority of Indian Green Building Council (IGBC) since 2001. It has licensed the Leadership in Energy and Environmental Design (LEED) from the U.S. Green Building Council. IGBC defines green building as one which uses less water, optimises energy efficiency, conserves natural resources, generates less waste and provides healthier spaces for occupants, as compared to a conventional building. IGBC certifies LEED-New Construction and LEED-Core and Shell buildings. It promotes a whole-building approach for sustainability based on the five elements of nature viz. sustainable site development, water savings, energy efficiency, material selection, indoor environmental quality. Since 2001, 1.4 billion sq. ft. of green space has been developed in India with 2,029 green buildings and 362 green rated buildings [12].

Furthermore, the Bureau of Energy Efficiency (BEE) and Ministry of Power, Government of India has launched the Energy Conservation Building Code (ECBC) in 2007. The purpose of the code is to provide minimum requirements for EEB design and their construction. It is estimated that ECBC-compliance buildings will consume 40-60% less energy than the conventional buildings. Mandatory enforcement of ECBC nationally will yield to saving of approximately 1.7 billion kWh. Load requirements for application of code include connected load of 100 kW or a contract demand of 120 kVA. Generally buildings or complexes having area under conditioning to be 1000 m^2 or more come in the scope of enforcement. The provisions of code are applicable to building envelopes, except for unconditioned storage spaces or warehouses; mechanical systems and equipment including building envelope; HVAC; service hot water heating; interior and exterior lighting; electrical power and motor. Implementation of ECBC is voluntary and local and state governments share the responsibility of its implementation. However, Ministry of Environment and Forests requires ECBC compliance for environmental clearance of major projects [13].

4. Barriers to EEB in India [10]

In spite of beneficial nature of EEB and effective ECBC, the development of EEB on a macro-scale is challenging. The barriers to EEB include:

4.1 Lack of information and awareness

A lot of misconceptions about the initial investment, cost-savings and benefits prevail among the owners, planners, banks and real estate developers. This deprives them from having insight of the energy savings, cost-savings and benefits, marginally high initial investment and health related benefits. Lack of reliable information and spread of owner-oriented information is a major barrier to wide-spread EEB development.

4.2 Lack of technical guidelines and availability of technology

There is a lack of technical and skilled expertise for providing information on issues of EEB and issues pertaining to it. It impedes the development of skilled human capital working on EEB. This inhibits the growth of energy efficiency both-at planning and at construction level.

4.3 Substantial initial investment

EEB requires about 15-20% higher initial investment as compared to conventional buildings. Also the owner is interested in quick returns on investment whereas the energy efficiency technologies are long-term based and the returns are not grandiloquent. Thus it hides the actual benefits of EEB and hinders the adaptation of EEB.

4.4 Lack of motivation and incentive

Convenience and inertia jointly affect the adaptation of EEB. Since the adaptation of ECBC is voluntary and only a few incentives to the builders exist, there is a lack of motivation on the customer as well as the developer side in the real estate market in regard to EEB.

5. EEB scenario in Germany and China

5.1 Scenario in Germany

The buildings in Germany are old and also the population is declining and therefore efficiency in existing buildings is of prime importance. Germany is located in the region of wet and cold winter and warm summer. Thus the major energy demand required is for space heating. Thus energy efficiency is majorly based on efficiency in spacing heating. As a consequence to this, EEB in Germany include retrofit of thermal envelope, replacement of heating system in existing buildings. District cooling system is responsible for small but important fraction of energy consumption.

The energy efficiency related policies include a target to reduce the primary consumption by 80% by 2050 for the building sector. Mid-term goals include reducing heating demand by 20% by 2020; ensuring climate responsive new buildings by 2020. A number of information instruments have been designed to support and create awareness among stakeholders of the EEB. Energy efficiency building code has been introduced by Energy Savings Ordinance to reduce thermal energy demand in new building. The code has set standards for primary energy usage and allows the building owner to regulate a grouping of insulation, heating and ventilation systems, and potentially integrated renewable energy to achieve this objective. To help overcome high upfront costs, the Energy Efficient Construction Program of the KfW Bank Group provides preferential loans, including loans for new buildings that significantly surpass the building standard. In recent times, the country has introduced a policy for integration of renewable energy for space heating. The Market Incentive Programme Renewable Energies (MAP) provides assistance to overcome cost barrier with subsidy to promote small scale installation of renewable heating system [14] [15].

5.2 Scenario in China

In the last decade, China has witnessed rapid growth and urbanization. Consequently, both – residential and commercial spaces have more than doubled in the period of 2000 to 2008. Thus energy efficiency in China is largely focused on new buildings. Most buildings in China are heated with district heating system with large commercial buildings having mechanical whole-building HVAC. Energy demand in China has almost tripled from 1996 to 2008. With the growth and development of the country, this demand is also expected to increase. The challenges in front of China include ensuring energy efficiency in new buildings at low cost; improving the efficiency of technology; provision of incentive for energy conservation in district heated buildings; to promote traditional techniques of ventilation and space heating. China has made an effort to increase compliance in HVAC systems and govern envelopes in new buildings. China encourages voluntary appliance labelling program. Income tax incentives and administrative measures promote efficiency of equipment and energy management in buildings. Financial support required for these actions are provided by various levels of the government [16] [17].

6. Decentralized Energy Generation (DE) concept

6.1 Definition

Different institutions or societies have defined DE in various manners, the definition we have adopted is the one given by the IEA. Thus the DE is defined as, generating plant serving a customer onsite or providing support to a distribution network, connected to the grid at distribution-level voltages.

The purpose behind using the DE concept is to provide an alternative power source to the conventional centralised generation. Thus, the location of the power generation has to be close to the load that is to be directly connected to the distribution network or on the customer end of the meter.

6.2 Need to go for Decentralised Energy Generation (DE) system over conventional centralised energy generation system

The existence of the alternative energy resources has led towards a more competitive system with an increasing amount of market participants, and given the increased environmental awareness, all electricity users require a more efficient, economic, environmentally-friendly and secure power supply system. Additionally, the constant growth in electricity demand in Europe as well as other countries around the globe is putting the electric power system – from generation to transmission to distribution - under strain. This leads to go for the alternate energy system which in turn would be able to reduce the strain over the conventional system. The general approach to address these issues and to meet the increasing demand was to add new power capacity to the system which in general implied the construction/upgrading actions of the following system components:

• Large generation units (i.e. Centralised fossil fuel based power plants);
• Long transmission lines with high carrying capacity, connecting large power plants with generally distant substations (which in turn lead to huge transmission losses about 33 % in India as compared to globally 15-16%).
• Short distribution lines with limited carrying capacity, connecting distribution substations with generally passive customers (i.e. users not able to produce power).

This approach in turn requires additional amount of fossil fuel, considerable amount of land to build power plant, and huge amount of capital investment. Thus this shortcomings force the administration to go for the alternate energy system which in turn would be able to reduce the strain over the conventional system [18]. One possible solution for this ambiguity is to go for the DE system.

The DE system basically focuses on the distributed generation, also known as dispersed or decentralised generation. Countries around the globe have started to shift away from conventional centralized, fossil-fuel-based power generation in favour of renewable-energy sources and distributed generation resulting by a confluence of forces—chief among them being

- environmental concerns,
- worries over energy security, and
- Advances in technology.

Energy storage is an essential requirement while using the intermittent renewable energy plants for energy production when the energy production through renewable resources exceeds the users' demand. Thus the additional energy production has to be stored by some means such as battery storages which provide the distributed system to store the energy thus produced and supply back to the grid during peak hours. The on-site storage availability thus reduces the difficulties in controlling supply to best match the demand which is led by adding more generating sources to the decentralised system.

The BCG report noted that in Germany as the energy production have started to shift towards DE system from centralised generation the dependence on foreign fuel will fall sharply, for example gas consumption for supplying power, for instance, will fall to 50 terawatt-hours in 2030 from 200 terawatt-hours in 2010. Germany's carbon footprint will also improve significantly as it pursues its emissions goals, which include a 55% reduction in greenhouse gas emissions from 1990 levels by 2030. The growing prevalence of distributed generation—by 2030, roughly half of Germany's power will likely come from distributed sources, such as rooftop solar panels and wind farms, compared with roughly 15% in 2011—will make the self-supply of electricity an increasingly viable option for individual German homeowners, industry, and possibly entire communities [19] [20].

The most important advantages inherent to the DE concept may be grouped and summarised as in the following points:

Authorisation and construction facilitation: It is generally easier to find sites for RES and other DE than for large central power plants and such units can be brought online much more quickly.

- Additionally, The DE system can be connected to central grids which have their own power production capabilities and excess generation could be sold to the grid or a mini-grid. This link-up of DE resources through a grid system improves its reliability especially when using intermittent renewable resources.
- Technical aspect: It provides planning flexibilities due to their small size and short construction lead times as compared to larger central power plants. Through on-site energy production, consumers of energy become producers and have a greater economic stake in efficient production and consumption. Smart meters make consumers more conscious about the energy they use thus leading to accelerate energy efficiency measures.
- Environmental aspect: Renewable and/or efficient DE can reduce fossil fuel consumption and greenhouse gas (GHG) emissions. Further, the use of CHP, made possible through the

decentralizing of electricity production, also increases the overall heat and power system's efficiency and thereby reduces harmful greenhouse gas emissions.

- Social aspect: Through DE system rural electrification is possible without having grid connectivity, thus it can lead to faster inclusive progress of the nation.
- Economic aspect: it offers lower capital costs as compared to centralised generation. It also leads to reduce the transmission and distribution losses which substantially will reduce the cost of energy generation. It can also stimulate competition in supply allowing more players to enter the electricity market. Further, Decentralized siting of energy generation facilities requires decentralized businesses to construct, operate and maintain the facilities, creating opportunities for local business and job creation [21].

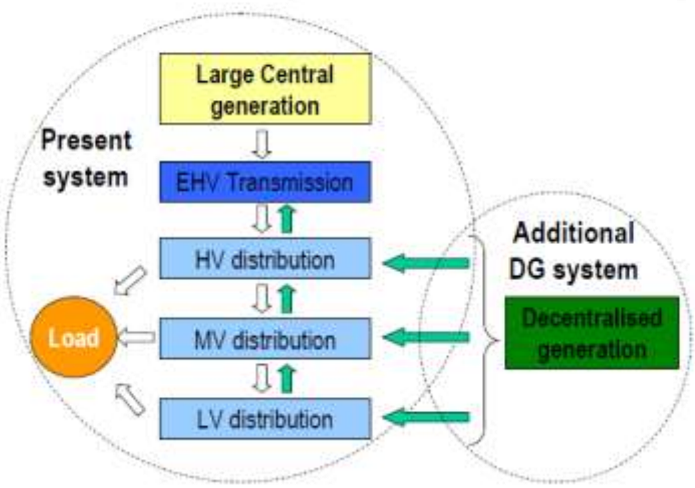

Fig. 2. Present grid architecture complemented with DG system [18]

6.3 Reforms proposed for EEB grid-connected DE in India

- Tax incentives including reduced stamp duty or business rates for properties proficient of generating their own electricity and expanded capital allowances for businesses.
- Newly coming up buildings can be enforced to implement DE technologies. This would progressively reduce GHG emissions from the building and enable the retirement of power stations, while also transforming the economics of DE by generating economics of scale and cutting installation costs.
- Government subsidy can be granted to owners implementing ECBC along with early clearance of building plans and issue of Building Use (BU) certificate at local level.
- All electricity suppliers can be enforced to purchase electricity from surplus DE installations.
- Encouraging feed-in tariffs can be implemented at initial level to escalate the growth of grid-connected DE.
- Area-based CO_2 emission targets can be set along with along with all states and local government to develop an energy strategy.
- Establishment of policy for grid-connected DE at national and state level.
- Setting targets to achieve reduction on energy generated from fossil-fuel based power plants.
- Sanction of approval to newly coming up industries shall be issued only on agreement of grid-connected DE installation.
- Incentive to DE installing real estate developers in the form of reduced stamp duty, early issue of land clearance, more FSI etc.

Conclusion

The study finds the benefits and barriers to the EEB and DE in India. We find that building sector has a huge potential to act as secondary power source for India. Primarily implementation of architectural reforms and use of advanced energy efficient technology can help reducing the energy demand.

Furthermore renewable DE can be used for generation of energy required for on-site use. Grid-connectivity of the DE will ensure reliable connectivity of the DE systems with the grid thus deficient power can be extracted from the grid as and when required and vice-versa. The cost of DE installation is much lower as compared to conventional centralized power plants thus encouraging installers and also promoting economic power generation. It will open up the market for small and medium players for energy trading and/ invest in to the energy market. Since the utilization of the generated power is on –site, the T&D losses occurring in the conventional power distribution system are significantly reduced. Apart from power sources, EEB with grid-connected DE also has the potential to reduce the GHG emissions due to use of clean energy for power generation and also due to use of environmentally conscious building material, the embodied carbon content of the building is also reduced. Looking on the EEB scenario of China and Germany, India needs to develop an aggressive approach towards wide-scale implementation of ECBC and promotion of energy efficiency in buildings. As well, energy efficient technology up gradation needs to be done keeping in to scope the system as a whole. District level heating and cooling system can be implemented to optimize the heating and cooling requirements using renewable energy sources. Setting of targets for demand and GHG reduction in buildings can be used as enforcement for the upcoming buildings to ensure energy efficiency at the foundation level itself.

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Correlating the state indoor air quality of buildings with large HVAC systems with the energy consumption

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Abstract

In the framework of iSERV (Inspection of HVAC systems through continuous monitoring and benchmarking), an Intelligent Energy for Europe project, a compact Indoor Air Quality system was developed and placed in buildings with HVAC systems larger than 12kW in different European metropolitan cities in order to investigate the relationship of IAQ and energy consumption. The sensor monitored continuously temperature, relative humidity, CO2 and level of VOCs while energy monitoring systems were also engaged to provide information on the building and HVAC system energy consumptions. The selected buildings were conveniently classified on the basis of the energy consumption and the air quality level into 3 categories. In offices, 24 IAQ systems have been installed, which were in operation from 3 to 10 months, while in Super Markets 23 IAQ systems have been placed, monitoring from 3 to 9 months. The results showed that the majority of office systems recorded low values of CO2, indicating that these buildings have a good indoor air quality, except for 4 offices that indicated that more than 25% of the recorded values were over 1000 ppm because of smoking. Furthermore, in Super Markets the indoor air quality seems to be good, apart from 3 markets that recorded the majority of their values over 600 ppm, indicating an acceptable indoor air quality. Moreover, in Media Markt stores 6 IAQ systems have been installed, monitoring from 5 to 6 months and the results also showed that the indoor air quality is good and ventilation is adequate. Furthermore, the monthly range of Volatile Organic Compounds (VOCs) in offices and in Media Markt indicates that the air quality of the majority of them is very good. In contrast, in Super Markets the Indoor Air Quality could lead to possible irritation or discomfort depending on the interaction with the other factors, probably due to emitting products.

1. Introduction

The poor indoor air quality is widely regarded as an important problem for health, environment and economy for both developing and industrialized countries. There is no precise definition for the quality of indoor air, but usually refers to the internal environment of non-industrial buildings, such as office buildings, public buildings (schools, hospitals, theaters, restaurants, supermarkets, department stores, etc.) and private residences and is «the totality of attributes of indoor air that affect a person's health and well-being» (Wesolowski, 1987). Indoor air quality indicators should therefore determine how well indoor air (a) satisfies the thermal and respiratory requirements, (b) prevents unhealthy accumulation of pollutants, and (c) allows a sense of well-being. (S.K. Brown, 1997).

According to research (California, USA 1988), in the industrially developed countries, people spend on average 80-90 % of their time in indoor environment (Figure 1). The percentages differ slightly.

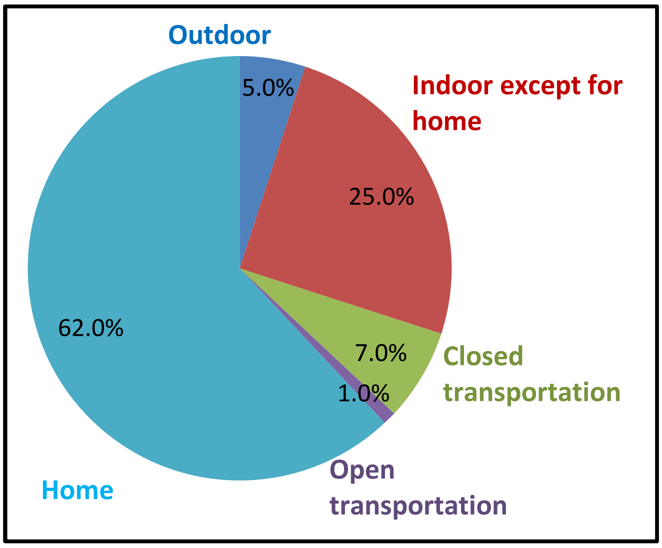


Figure 1: Time distribution indoors and outdoors

depending on the kind of the target group. For example, housewives, the elderly and preschool children spend more time at home, while the workers divide their time they spend indoors between home, workplace and transportation.

Almost all studies found that ventilation rates below 10 Ls-1 per person in all building types were associated with statistically significant worsening in one or more health or perceived air quality outcomes. Some studies determined that increases in ventilation rates above 10 Ls-1 per person, up to approximately 20 Ls-1 per person, were associated with further significant decreases in the prevalence of sick building syndrome (SBS) symptoms or with further significant improvements in perceived air quality. The carbon dioxide studies support these findings (A. Seppänen et. al, 1999).

Studies in Australia, where measurements among other of volatile organic compounds and carbon dioxide have taken place, show a poor indoor air quality due to (low) building ventilation rates and (high) emission from pollutant sources. (S.K. Brown, 1997).

Williams (1992) investigated ventilation system adequacy in 228 suburban, low-rise office buildings in Melbourne and, while illness was not specifically assessed, it was reported that occupants of 62% of buildings experienced unacceptably stuffy, drowsy conditions. A similar incidence has been observed for inadequate ventilation of commercial buildings in Perth (K. Collins, BCA Consultants, Perth). Also it has been reported (D. McKenna, Community and Public Sector Union, unpublished paper) that a multi-State survey of 511 Commonwealth Government office workers in 1990 found that 91% experienced discomfort or illness associated with poor ventilation or temperature control. Complaints included: too hot (72%), too stuffy (72%), drowsiness (48%), headaches (48%), and sore throat (55%).

Another study was performed in 270 work spaces belonging to 30 office buildings of various German cities during the period October 2004 – October 2006. About 50% of values were above 700 ppm; besides, there was a little variation among values. On the one hand, 10% of values measured at natural ventilated spaces and 4% in mechanical ventilated spaces are below the 600 ppm limit. On the other hand, in natural ventilated spaces, about 15% of values were above the 1000 ppm. In mechanical ventilated spaces, this limit was surpassed by only 10% of the readings. From these accounts, it can be stated that about 75% of cases in natural ventilated spaces and 86% in mechanical ventilated spaces, the CO2 concentration were between 600 and 1000 ppm (S.K. Brown, 1997).

The quality of indoor air is determined by a number of parameters such as:

- The indoor concentrations of radioactive elements.
- The internal temperature and relative humidity.
- The rate of exchange of indoor air with the environment.
- Noise, vibration, artificial light, odors or the existence of extremely low frequency electromagnetic radiation. (WHO, 2000)

Many residents or workers in buildings complain about the quality of the air they breathe, creating the need for further investigation of the situation. Since 1984 the World Health Organization Commission (World Health Organization-WHO) concluded that 30% of new or remodeled buildings worldwide exhibit at least some characteristics of the «Sick Building Syndrome» (SBS). (Tom Redman and Peter Hamilton, 2011).

The symptoms of SBS can be very serious, although they do not generally have a permanent effect. Studies report that the problems of SBS range from simple discomfort (headache, cough, dry eyes, stuffy/runny nose, fatigue unnecessarily rash/itching, colds/flu, sore throat and shortness of breath) to the permanently disabled workers. There is also evidence to confirm the relationship between SBS and the stress of work, which is generated by work in a Sick Building (Bauer et al., 1992). Furthermore, studies have linked negative emotional reactions (resentment, anxiety and confusion, disbelief) of workers in sick buildings compared with workers in non - SBS environment (Bauer et al., 1992). Moreover, good working conditions have beneficial effects not only on workers' health and wellbeing, but also the productivity of workers and the quality of work produced (Fisk and Rosenfeld, 1997) (Tom Redman and Peter Hamilton, 2011).

According to the World Health Organization (WHO) people who spend long hours in sealed buildings and experience the sick building syndrome ‘cost society more than it gains by reducing energy consumption’. Therefore, most of the above symptoms should disappear within a few hours of the removal of this building (Brian Crook and Nancy C. Burton, 2010).

2. Description of the Experiments

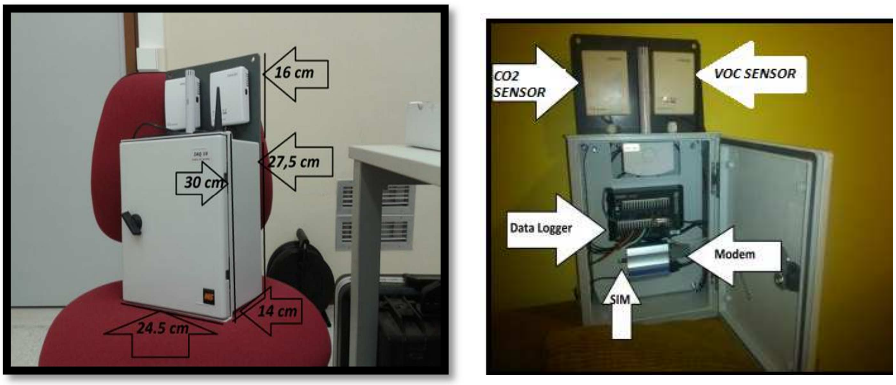
2.1 Sensor

IAQ stations - F2000TSM-VOC-L series is specially designed to detect low IAQ levels in working and living environment and to further transmit the detected low IAQ levels with a corresponding analog output or to control a ventilator by an on/off output as pre-set IAQ level. Its internal mixed gas sensor (normally called VOC sensor) is very sensitive to VOC concentration in the air (VOC i.e. Volatility Organic Compound, such as timber, dope and toluene emitted by building materials), and other air pollutants such as cigarette smoke, ammonia and H2S. It also has high sensitivity to CO, alcohol, natural gas and odorous smells from human bodies. Compared with other single air sensor, Tongdy F2000TSM-VOC series is more suitable for IAQ monitoring in a long run. This sensor has response 1 minute and records spot values every 15 minutes and hourly mean values for all parameters (figure 2).

2.2 Data collecting

This sensor has a modem connection to the internet, a data logger and a SIM card, the number of which is characteristic for each IAQ kit. To collect the data from each IAQ kit there are two ways to connect to this kit, the connection via cable and the connection via modem. The first one requires an RS232 cable which is directly connected to the IAQ kit and then via the PC200W software we collected the data. The second one required an internet connection, via LoggerNet 4.1 software.

Figure 2. The IAQ measuring kit



2.3 Methodology

Initially the IAQ kits were calibrated for VOC and CO2 measurements in order to ascertain the validity of their outputs. (figure 3 and 4). Moreover, a set of 20 IAQ kits were placed in a pilot building for 4 months in order to determine the validity of the results in relation to the existence of one or more IAQ kits. The same comparison was also made in Super Markets in which 4 IAQ kits have been installed.

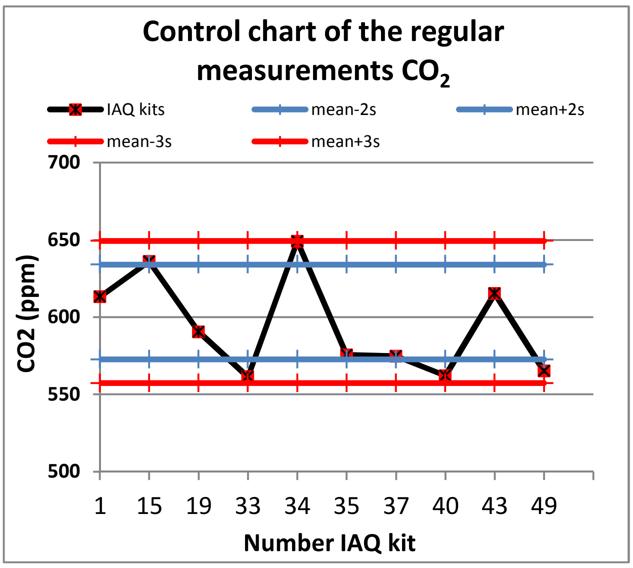


Figure 3: Control chart of the CO22measurements

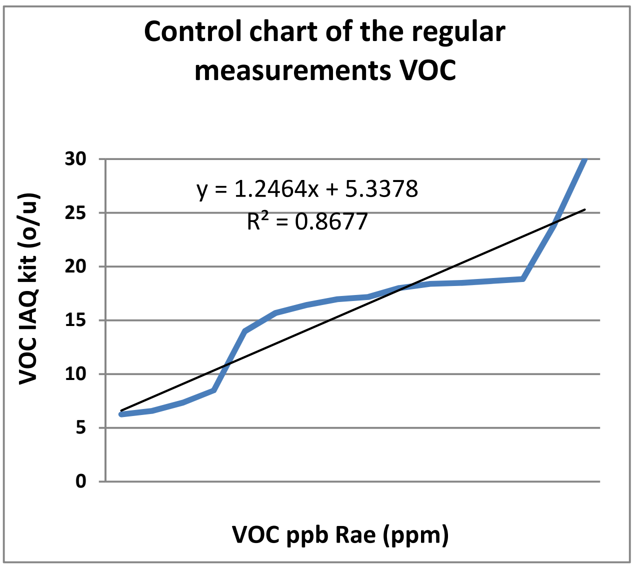


Figure 4: Control chart of the VOCs measurements

The limits for the VOCs were based according to Molhave, (Table 1), while the limits for the CO2 were selected according to the CIBSE guides (table 2).

Table 1: Molhave Scale in correlation to IAQ kit output

Total concentration	*Sensor output (o/u)*	*Discomfort and Irritation Show*	*Exhibition scale*
Less than 0.2 mg/m³ (Less than 0.05 ppm)	*Less than 10*	*No irritation or discomfort*	*Comfort Scale*
From 0.2 mg/m³ to 3.0 mg/m³ (from 0.05 to 0.80 ppm)	*From10 to 20*	*Possible irritation or discomfort depending on the interaction with the other factors*	*Scale Exposure to multiple factors*
From 3.0 mg/m³ to 25 mg/m³ (From 0.80 to 6.64 ppm)	*From 20 to 30*	*Symptoms - Possible headaches depending on other factors*	*Discomfort Scale*
Over 25 mg/m³ (Over 6.64 ppm)	*Over30*	*Additional neurotoxic effects may occur, apart from the headache*	*Toxic Exposure Scale*

Table 2: Carbon dioxide scale

IAQ	*CO_2 Concentration [ppm]*
Good	*<600*
Acceptable	*600 – 1.000*
Bad	*>1.000*

Moreover, the daily and monthly values of all IAQ kits per building category were calculated (offices, Super Market, electronics stores). The diagrams also show the limits for each pollutant so that the days in which the limits were exceeded can be identified.

Next step was the seasonal distinction in winter and summer period, and depending on the operating hours of each building they were separated into day and night mode. Regarding seasonal distinction, it could be referred to as 'winter' period the period October 2012 to April 2013 and October 2013 to December 2013 and as 'summer' the period March 2013 to September 2013, while for separation based on the hours of operation of each building, those listed in the following Table 3:

Table 3: Day and Night mode

	Day mode (morning)	*Night mode (night)*
Super market	*7:00 – 22:00*	*22:00 – 7:00*
Offices	*8:00 – 18:00*	*18:00 – 8:00*
Electronics Market	*9:00 – 22:00*	*-*

2.4 Building Data

The buildings were selected according to the type of use of the building (3 different categories: offices, Super Market and electronics stores). The measurements were performed for more than a year (September 2012 to January 2014) (Table 4).

Table 4: Building data and measurements period

Building Type	Region	Address	Number of IAQ kits	Start date	End Date
Super market	Ag. Paraskevi	Mesogeiwn Av. 430	3	October 2012	December 2013
			1	October 2012	January 2013
	Ag. Dimitrios	Komninwn 1 & Ethnomarturwn	4	October 2012	December 2013
	Chalkida	Chaina 251	1	November 2012	December 2013
	Virwnas	Karaoli Dimitriou 34	1	November 2012	December 2013
	Pagkrati 1	Spyrou Merkouri 38 & Ergotimou	1	November 2012	December 2013
	Pagkrati 2	Alketou 5	1	November 2012	December 2013
	Petralwna	Alkminis 5	1	November 2012	December 2013
	Gluka Nera 1	Lauriou Av. 113-115 & Leontariou	1	November 2012	December 2013
	Peristeri 1	Ethnarchou. Makariou 54	1	November 2012	December 2013
	Korudallos	Serrwn 6 & Palaiologou 2	1	November 2012	December 2013
	Peuki	Eirinis Av. 48 & Korai	1	April 2013	October 2013
	Patisia - Radio City	Patisiwn 240	1	April 2013	December 2013
	Fulis	Fulis 245 & Olumpias 27	1	April 2013	December 2013
	Peristeri 3	Farsalwn 43	1	April 2013	June 2013
	Ampelokipoi	Konopisopoulou 19 & Geroulanou	1	April 2013	December 2013
	Gluka Nera 2	Lauriou Av. 160 & Chrusanthemwn	1	April 2013	December 2013
	Stamata	Drosia Av. – Stamatas 31^A	1	April 2013	December 2013
Offices	Offices 1(pilot building)	Peloponisou 5(test measurements)	20	September 2012	October 2012
			19	September 2012	November 2012
			18	September 2012	December 2012
		Peloponisou 5	12	September 2012	February 2013
			7	September 2012	April 2013
			2	September 2012	December 2013
	Offices 2	Akadimias	1	January 2013	December 2013
	Offices 3	Old Spatwn Av. 81	1	April 2013	December 2013
Offices	Offices 4	Dwdekanisou 14 & Ikoniou Alsoupoli	1	October 2012	December 2013
			1	October 2012	November 2013
	Offices 5	Leontos 4 & Eleftherias	1	December 2013	November 2013
	Offices 6	N.K.U.A	1	September 2013	October 2013
Electronics Market	Renti	Kifisou Av. 161	1	December 2013	December 2013
	Peristeri	Athinwn Av. 64 & Thivwn 25	1	January 2013	December 2013
	Marousi	Kifisias Av. 49	1	January 2013	December 2013
	Gerakas	Marathwnos Av. 149	1	January 2013	December 2013
	Alimos	Syggrou Andrea Av. 340	1	December 2013	December 2013
	Kallithea	Leontos 4 & Eleftherias	1	February 2013	December 2013

3. Results and Analysis

The frequency distribution shows a summarized grouping of data divided into mutually exclusive classes and the number of occurrences in a class. It is a way of showing unorganized data. Frequency distributions are used for both qualitative and quantitative data.

3.1 CO2 Frequency Distribution

The results showed that in the majority of Super Market, the air quality is good while there were three stores which were classified in the category of 'Acceptable Quality'. Moreover, only three shops exceeded more than 25% of their values the limit of 1000 ppm. Furthermore the majority of offices and at all electronics stores the air quality is good. However, 4 offices exceed more than 25% of the values the limit of 1000 ppm, which is due to smoking in these areas. The ventilation of these buildings is generally adequate with some minor exceptions. The results are shown to the table 5, while the total charts for each category of building are given below (figures 5-7).

3.2 VOC Frequency Distribution

The results showed that in the majority of Super Market the air quality can lead to possible irritation or discomfort depending on the interaction with other factors, while there were two stores which were classified to the category 'Symptoms - Possible headache depending on other factors'. Furthermore, 8 stores exceeded more than 25% of their values the limit of 20 o/u. In most of the stores that showed high VOC values, measurements were made near detergents, animal food and toiletries, which justifies these high values. Furthermore in the majority of offices and in all electronics stores the air quality does not lead to any irritation or discomfort, while there were some offices with values corresponding to the category 'Possible irritation or discomfort depending on the interaction with other factors'. Only one office exceeded the limit of 20 o/u by more than 25% of the values because of the existence of photocopiers and printers in this office. The results are shown to the table 6, while the total charts for each category of building are given below (figures 8-10).

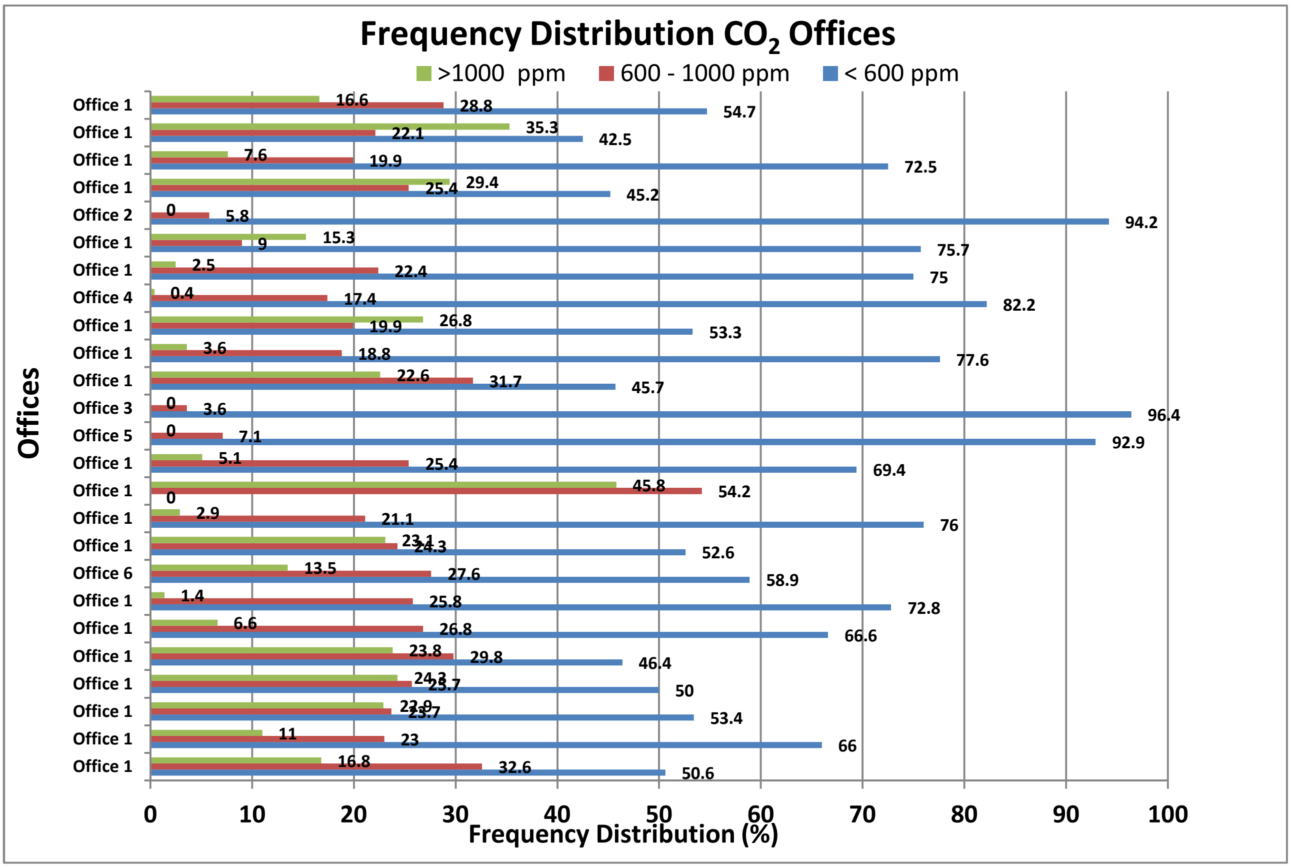


Figure 5: Frequency Distribution in Offices

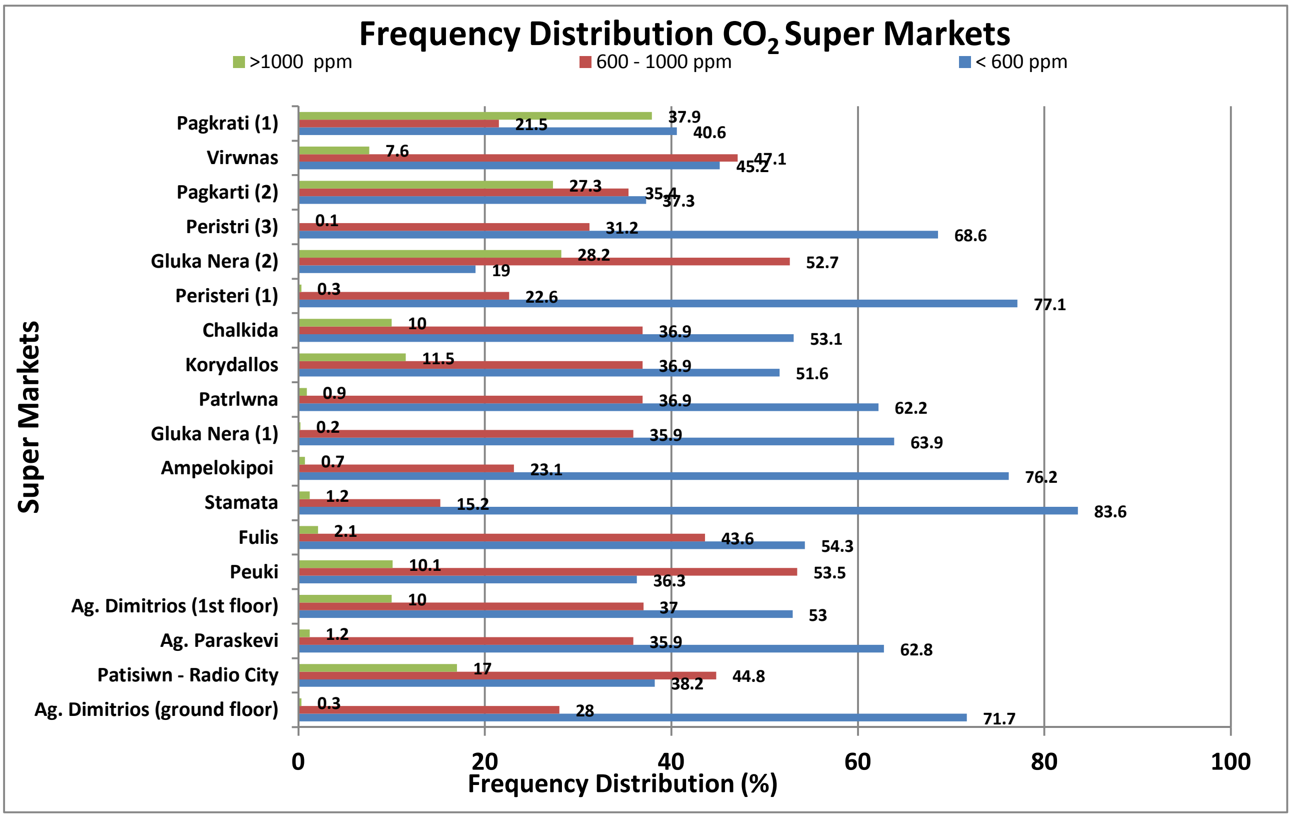


Figure 6: Frequency Distribution in Super Markets

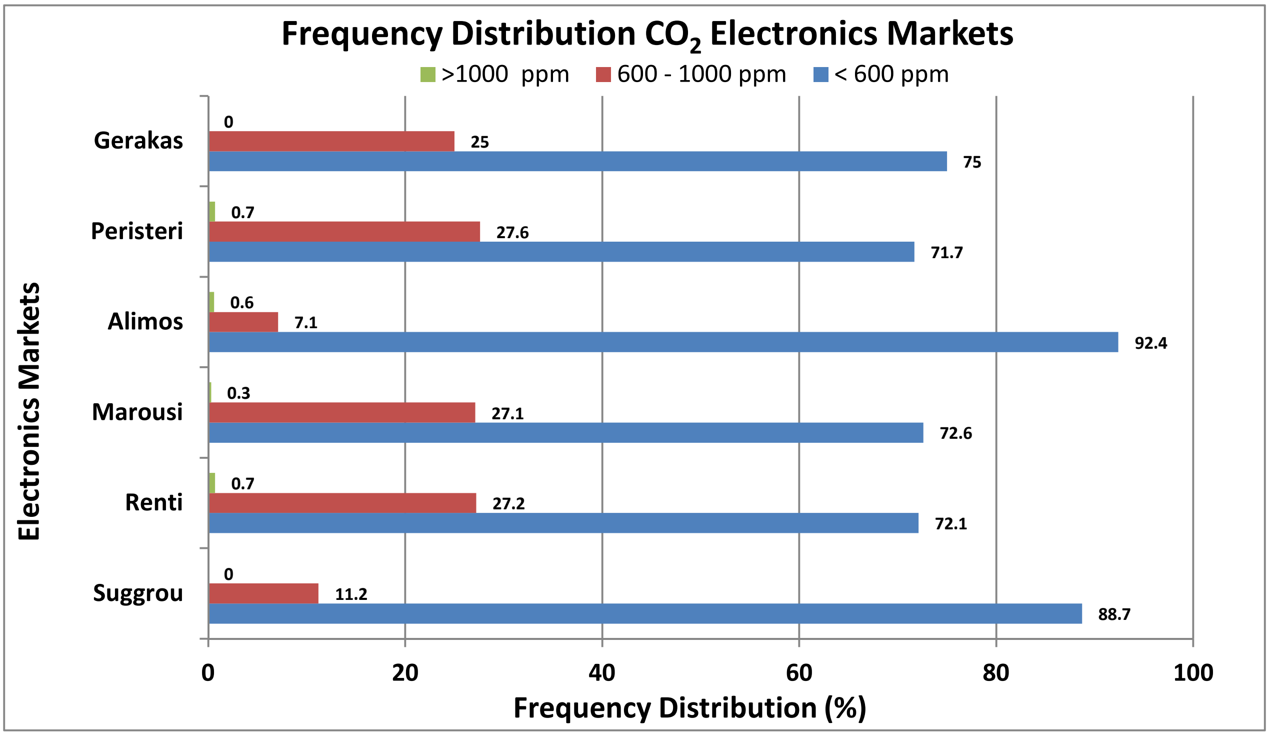


Figure 2: Frequency Distribution in Electronics Market

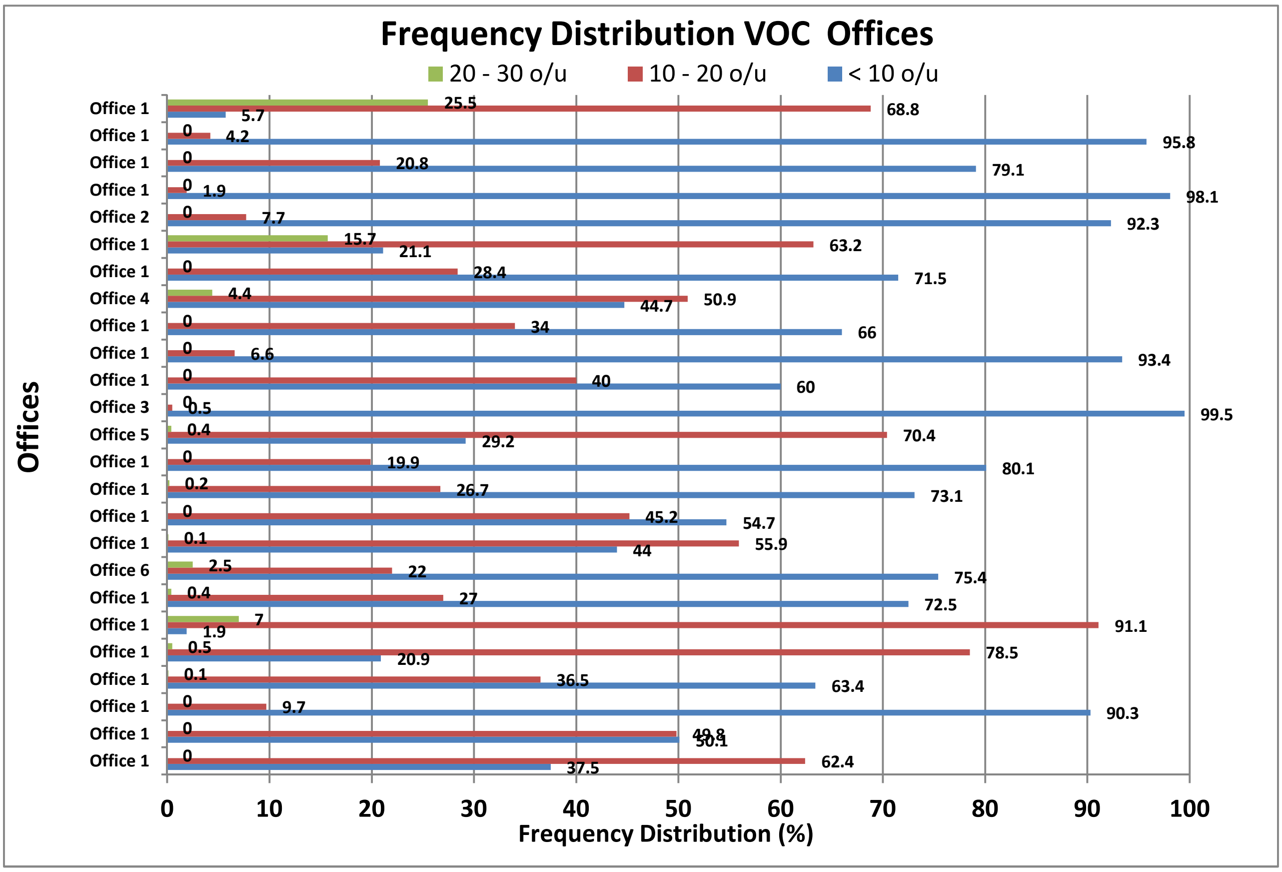


Figure 8: VOC Frequency Distribution in Offices

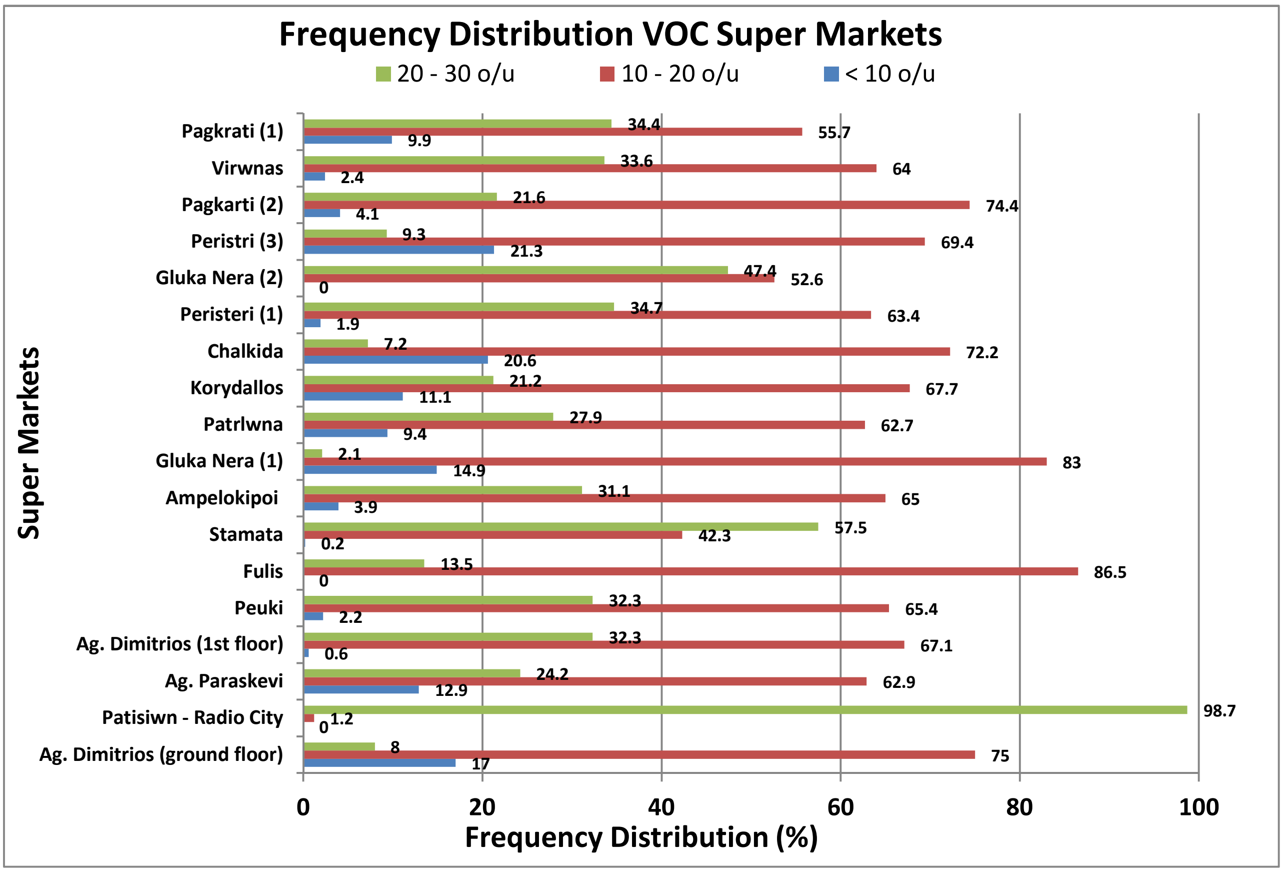


Figure 93: VOC Frequency Distribution in Super Markets

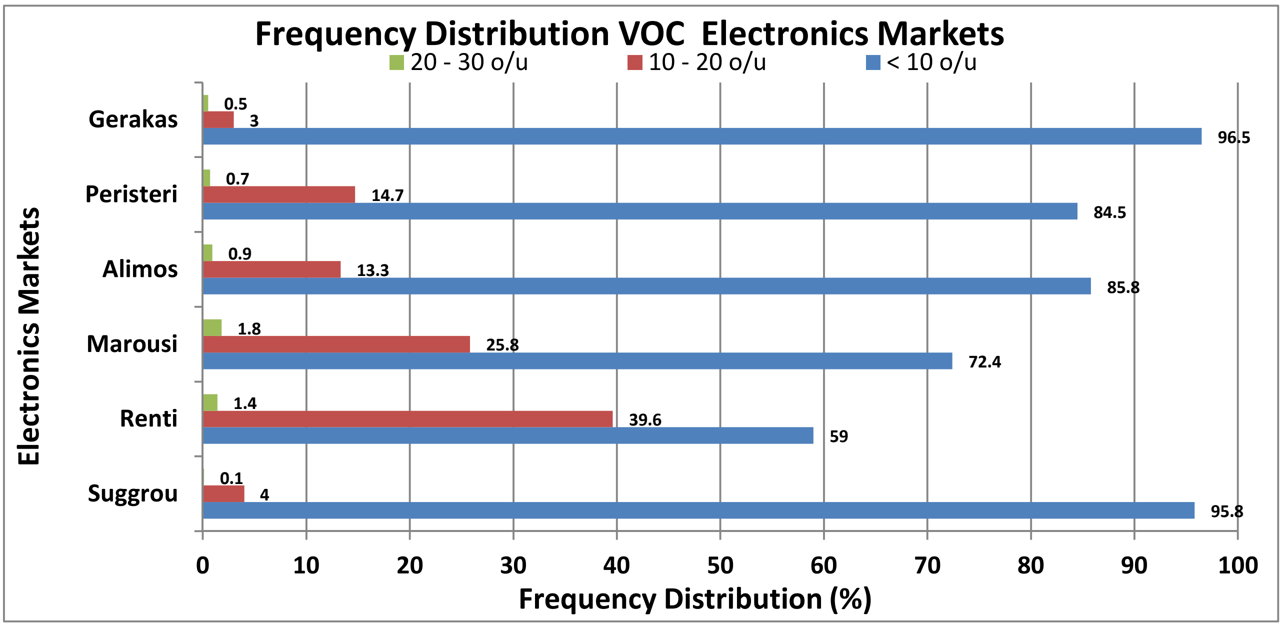


Figure 4: VOC Frequency Distribution in Electronics Market

4. Conclusions

In a nutshell, in the offices it is likely to have differences in measurements on the same floor due to either the different behavior of people who use the office (smoking, stoves), or the different use of each room (meetings ,kitchen). The differences in the CO2 levels are not significant, while the for the VOCs are slightly higher, because of the existence of sources of VOCs in some specific offices (printers, copiers), but they could not indicate huge differences in air quality. On the other hand, in Super Markets the installation of more than one IAQ kit is only of importance in the case were there are isles with emitting products i.e detergents, animal foods etc. and the values of VOC could differ significantly.

Furthermore, the study showed that only for 3 out of 16 months that the total measuring period lasted in offices, the majority of these buildings recorded values of carbon dioxide over 1000 ppm, while the majority of Super Markets and electronics stores recorded lower carbon dioxide levels. It is important to mention, that for 4 out of 15 months where measurements took place in Super Markets, some buildings of that use recorded values of volatile organic compounds leading to symptoms and headaches depending on other factors.

With respect to CO2, the results showed that in the majority of Super Markets, the air quality was good while there were three stores which were classified in the category of ‘Acceptable Quality’. Moreover, only three shops exceeded more than 25% of their values the limit of 1000 ppm. Furthermore the majority of offices and at all electronics stores the air quality is good. Though 4 offices exceed more than 25% of the values the limit of 1000 ppm, which is due to smoking in these areas. The ventilation of these buildings is generally adequate with some minor exceptions. On the other hand, the majority of Super Markets the air quality can lead to possible irritation or discomfort depending on the interaction with other factors, while there were two stores which were classified to the category ‘Symptoms - Possible headache depending on other factors’. Furthermore, 8 stores exceeded more than 25% of the time the limit of 20 o/u. In most of the stores that showed high VOC values, measurements were made near detergents, animal food and toiletries, which justifies these high values. Moreover, in the majority of offices and in all electronics stores the air quality were classified in the category ‘no irritation or discomfort’, while there were some offices with values corresponding to the category ‘Possible irritation or discomfort depending on the interaction with other factors’. Only one office exceeded the limit of 20 o/u by more than 25% of the values because of the existence of photocopiers and printers in this office.

In addition, in some office buildings despite the low levels of carbon dioxide at operation hours, higher levels were recorded at non – operating hours due to the presence of people in the area after the operation of the offices, suggesting that the ventilation system works properly during working hours and it is necessary for the specific building. Moreover, the observed level of volatile organic compounds in most buildings was higher during non-operation hours, because of the emission of materials and simultaneous sub mode of the ventilation system. The temperature was maintained at lower levels in the evening, with exception of some hot summer months, where the opposite trend occurred due to excessive use of air conditioners during the day.

Finally, the results also showed that in most buildings regardless of the type, carbon dioxide ranges at higher values during the winter season, due to more intense mobility of people at this period compared to the summer. In Super Markets a more constant trend of carbon dioxide during the summer season was observed, in contrast to the winter period that more fluctuations occured. Moreover, regarding volatile organic compounds, a relationship between the variation of this pollutant and the corresponding periods in any type of building was not established. It was also observed that the relative humidity remained constant throughout the duration of the measurements with small fluctuations, which might not be related to seasonality, while the temperature was maintained at constant levels (fixed Set point: 25 oC) in the Super Markets and electronics stores, in contrast to offices that recorded higher values during the summer season.

It is very important to note that all buildings where the IAQ kits were installed were fully air-conditioned and the opening of windows was not possible.

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Session

Lighting

IEA SHC Task 50 "Advanced Lighting Solutions for Retrofitting Buildings"

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Abstract

The savings potential of lighting retrofits is substantial. But without significant changes in policies, markets and practical implementations, the energy consumption is expected to continuously grow despite technical improvements like solid-state lighting, new façade and light management techniques. With a small volume of new buildings, major lighting energy savings can only be realized by retrofitting the existing building stock.

With IEA SHC Task 50: "Advanced Lighting Solutions for Retrofitting Buildings", the International Energy Agency (IEA) is pursuing earlier endeavors of the SHC-programme, this time with the overall objective to accelerate retrofitting of daylighting and electric lighting solutions in the non-domestic sector using cost effective, best-practice approaches, which can be used on a wide range of typical existing buildings. Over the course of the Task, participants from 14 different countries will collaborate to analyze relevant issues regarding the current lighting situation, lighting retrofit solutions and processes (technically, ecologically and economically), the market situation and potentials given. In addition, the different main stakeholders involved in the lighting retrofit market, need to be identified and addressed within Task 50.

Large Potential for Saving Electricity

Lighting accounts for approx. 19 % (~3000 TWh) of the global electric energy consumption. Without essential changes in policies, markets and practical implementations it is expected to continuously grow despite significant and rapid technical improvements like solid-state lighting, new façade and light management techniques. With a small volume of new buildings, major lighting energy savings can only be realized by retrofitting the existing building stock, where the majority of lighting installations are considered to be out of date (older than 25 years). Compared to existing installations, most new solutions allow a significant increase in efficiency – easily by a factor of three or more – going along with highly interesting payback times. However, lighting refurbishments are still lagging behind compared to what is economically and technically possible and feasible.

The activities of Task 50 aim at improving the lighting refurbishment process in non-residential buildings in order to unleash energy saving potentials while at the same time improving lighting quality.

Target Group: Stakeholders in Relighting

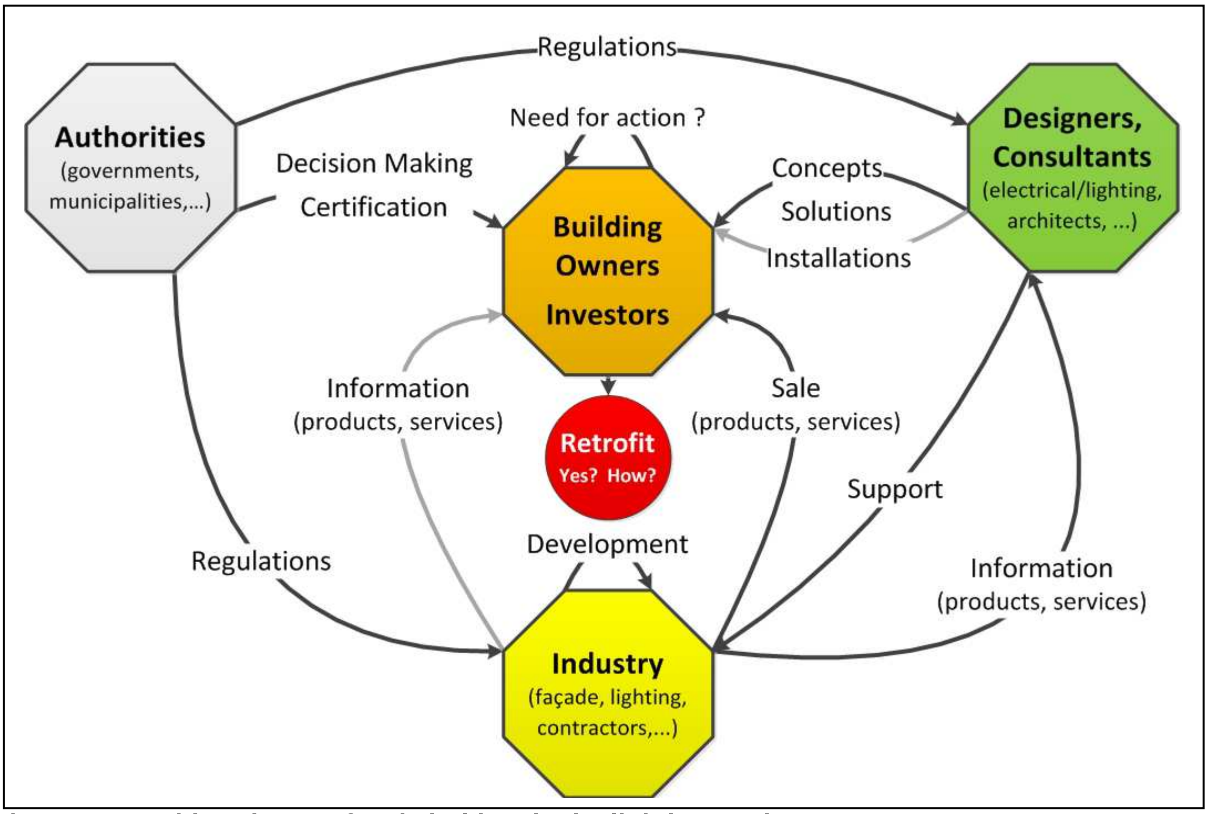

Figure 1: Graphic scheme of stakeholders in the lighting market

Different main stakeholders are involved in the lighting retrofit market, highly interconnected as depicted in figure 1. This leads to the following diverse interests and needs, which will be identified and addressed within the Task.

- **Authorities**, like governments and municipalities:
  Interest: Meet energy efficiency and $C0_2$ emission reduction goals
  Needs: As lighting only gradually gets into focus: Improvement of regulations, standards and certifications

- **Building owners / investors**:
  Interest: Optimization of total cost at different investment horizons/ payback times
  Needs: Transparent cost structures,
  additional values like "green image"

- **Industry**:
  Interest: Economic success by adapting products and services to market developments
  Needs: Changing focus on lighting services and integrated solutions

- **Designers / consultants** (e.g. architects, engineers):
  Interest: Providing optimal solutions for various cases
  Needs: Support in lighting design as part of complex design process with diversity of approaches

Activities to Get There

The overall objective is to accelerate retrofitting of daylighting and electric lighting solutions in the non-domestic sector using cost effective, best-practice approaches, which can be used on a wide range of typical existing buildings.

This includes the following activities, leading to the deliverables described below:

- Develop a sound overview of the lighting retrofit market
- Trigger discussion, initiate revision and enhancement of local and national regulations, certifications and loan programs
- Increase robustness of daylight and electric lighting retrofit approaches technically, ecologically and economically
- Increase understanding of lighting retrofit processes by providing adequate tools for different stakeholders
- Demonstrate state-of-the-art lighting retrofits (figure 2 shows new systems)
- Develop as a joint activity an electronic interactive source book including design inspirations, design advice, decision tools and design tools

Figure 2: New systems of lamps/luminaires and façades for retrofitting

Deliverables

Within the scope of Task 50, the following main deliverables are anticipated:

- Report on the lighting retrofit market, including policy issues and proposals of action
- Source book on daylighting and electric lighting retrofit technologies, covering low-budget and new advanced retrofit solutions
- Toolbox with (simple) methods and tools for energy and economic auditing, rating and performance simulation
- Documentation of realized projects and case studies of lighting retrofits for different building types

- "Lighting Retrofit Adviser"
  An electronic, interactive source book including design advice and recommendations, decision-making tools and design tools for lighting retrofits

Most deliverables will be available on the Task's website. In addition, Workshops and Newsletters will inform about progress and disseminate important outcomes.

Coordination

To manage the work of the participating 14 countries, SHC Task 50 is subdivided into the following four Subtasks with a Joint Working Group to connect the activities and combine all the results (as depicted in figure 3). Each Subtask is coordinated by a representative from a different country.

- **Subtask A:** Market and Policies
  Marc Fontoynont, Danish Building Research Institute (SBI), Copenhagen, Denmark
- **Subtask B:** Daylighting and Electric Lighting Solutions
  Martine Knoop, Technische Universität (TU) Berlin, Germany
- **Subtask C:** Methods and Tools
  Jérôme Kaempf[1] and Bernard Paule[2], Switzerland
  [1] Ecole Polytechnique Fédérale de Lausanne (EPFL)
  [2] Estia SA, Lausanne
- **Subtask D:** Case Studies
  Marie-Claude Dubois, Lund University, Sweden
- **Joint Working Group / Operating Agent**
  Jan de Boer, Fraunhofer Institute for Building Physics, Stuttgart, Germany

Figure 3: Structure of the IEA SHC Task 50

References

http://task50.iea-shc.org/

reLight - an efficient tool for on-site inspection of lighting installations and identification of potentials

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Abstract

The tool "reLight" allows assessing the lighting situation when doing a first on-site inspection of the building, enabling planners to evaluate first proposals for possible retrofitting measures with regard to energy consumption and cost considerations. The tool is based on research done with regard to lighting solutions in existing buildings and planned solutions for retrofit lighting systems, classification and typology. The lighting solutions were collected in a database. The tool is linked to an assessment model for energy-related and economic analyses. A user-friendly interface allows using this assessment model, which is linked to a database. reLight is not only suited for input and storage of lighting installation data of existing buildings (as a type of building inspection report), it also supports the user by providing graphical selection elements and descriptions as well as by continuously checking the consistency of the data entries made. In addition, the collected data describing the existing building situation and the proposed retrofit scenarios can be exported to be used in other applications; also, they can be documented as pdf-reports. reLight is available for download at the Google App Store website [1]. Further information is provided on the tool website [2].

Introduction

The majority of the electric energy consumption for lighting is consumed by old systems. Renovating these systems would yield huge energy savings of two thirds or more in many cases. To spot these potentials can be a time-consuming procedure and does not compulsory lead to a retrofit. To investigate lighting systems within buildings, Energy and lighting consultants have to go into and study every single room. So lighting experts have mostly to carry lots of printouts of checklists and fill them out by hand on site. This is why people often don’t bother to get an inspection of their existing lighting systems.

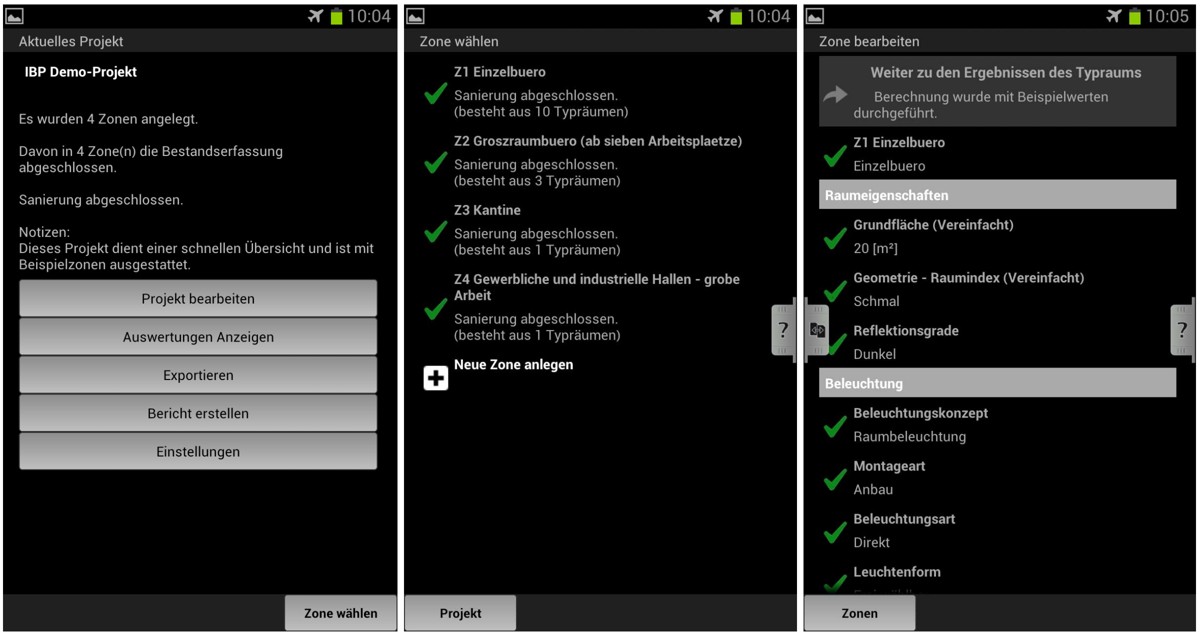
Target

It is the aim of the new app reLight for mobile devices such as tablet computers and smartphones to make this analysis work easier for lighting experts when inspecting buildings. It also offers other useful energy consultancy functions, such as creating cost comparisons over several years. An assessment of the existing lighting system is done by means of a visual comparison and a simple qualitative description of the room proportions and façade type. Within minutes this leads not only to an energy analysis of the existing lighting system, but at the same time to suitable renovation suggestions, including a separate statement of costs for each of the different proposals. Pre-parameterization and verification logic ensure that no invalid data sets are created and that results can be viewed quickly. The app features a multi-zone model that enables to assess and manage whole buildings. When there are several rooms of the same kind, only one of them has to be analyzed. This room serves as model for the others, which are calculated by multipliers to evaluate the building as a whole. Depending on the user’s interests, different renovation options per zone can be combined into an overall renovation, in order to obtain optimum energy and/or cost-efficiency results for the building. These results can be viewed numerically or also graphically depicted.

The Development of the app was sponsored by the German Federal Institute for Research on Building, Urban Affairs and Spatial Development within the research initiative ”Future Building” with support from the companies TRILUX and EnBW.

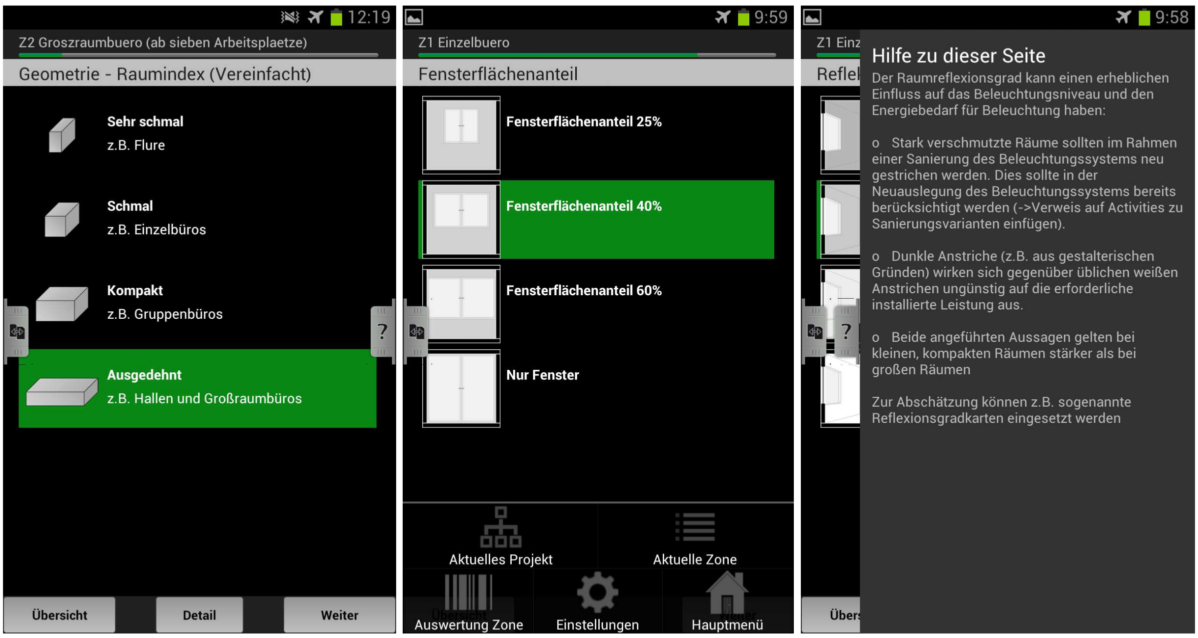
General performance characteristics

The App features the following performance characteristics and concepts for on-site recording of existing lighting installations and the subsequent assessment of energy-related and economic saving potentials when retrofitting lighting systems.



Screenshot showing cascading structure and plausibility checks

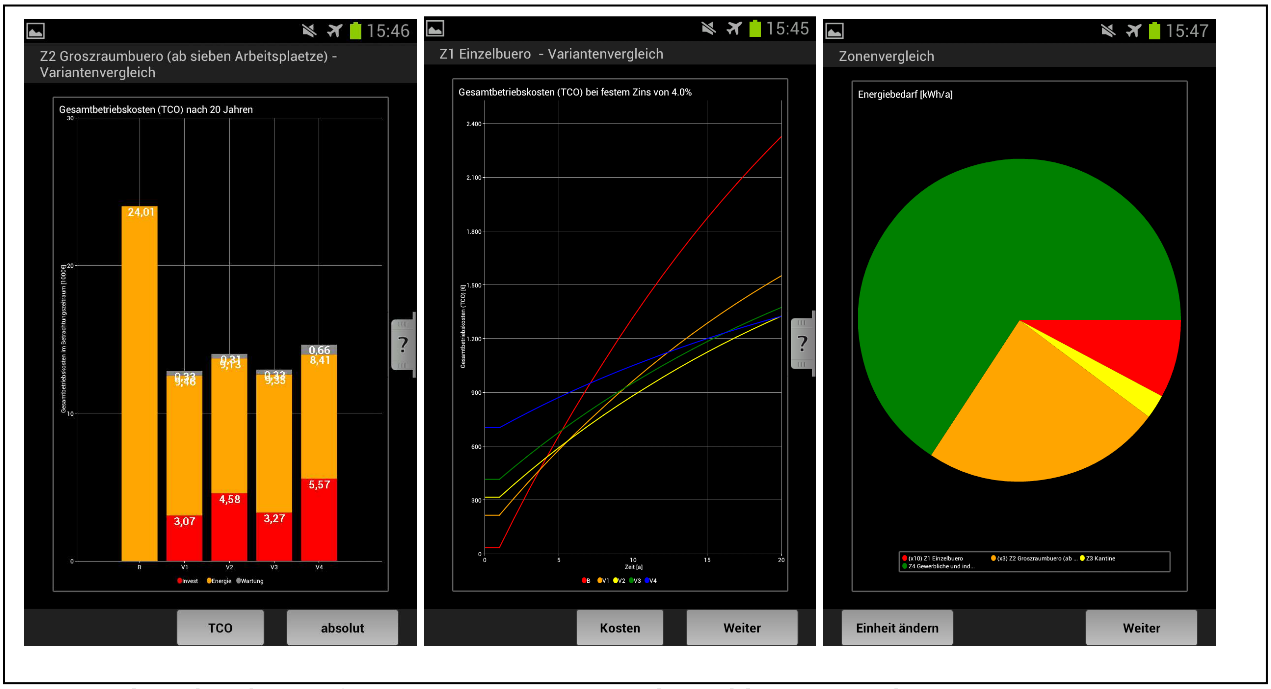
An optimized building inspection workflow allows for time-efficient reporting and assessment, supporting the user's selections by providing graphs, images, and explanations. Realistic data input is supported by continuously monitoring the technological connections (plausibility checks).



Screenshot showing graphical illustrations and detailed explanations

The simple, intuitive handling of the tool - thanks to its logical structure, the direct help, graphical illustrations, cascading screen structure (from easy access up to more detailed evaluation) - is achieved by not prompting any data that is irrelevant for energy performance rating.

Besides considering purely technical aspects, the automatic generation of variant retrofitting scenarios (including energy-related and economic evaluation [3]) is also based on decision matrices, which reflect optical expertise. The calculations are based on the latest standards (DIN EN 12464 [4] and DIN V 18599 [5]).



Screenshot showing performance parameters and graphical comparison

Due to the implemented multizone model it is possible to inspect individual spaces of the building and to summarize them for combined analysis. Depending on the user's priority, it is further possible to combine different variant retrofitting scenarios aiming to obtain optimum results with regard to energy performance or cost efficiency. This feature provides an individual decision-making aid for lighting solutions in separate rooms, according to the user's preference. Various parameters that are relevant to energy performance, climate, and cost efficiency (like absolute or specific delivered energy / primary energy needs, CO2 emissions, different types of cost, amortisation periods, Total Cost of Ownership, interest on capital) are graphically illustrated for each zone and for the entire project to provide the user with a clear overview of the project.

To avoid double input when further processing the collected data, there is an option that allows to export data to other applications. A reporting function produces a printable report including all relevant project data for review.

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[3] Verein Deutscher Ingenieure (Hg.): VDI 6025. Betriebswirtschaftliche Berechnungen für Investitionsgüter und Anlagen. Beuth Verlag GmbH, 1996

[4] Normenausschuss Bauwesen, Heiz- und Raumlufttechnik und Lichttechnik im DIN: DIN EN 12464 – Beleuchtung von Arbeitsstätten. Beuth-Verlag GmbH, Berlin, August 2011

[5] Normenausschuss Bauwesen, Heiz- und Raumlufttechnik und Lichttechnik im DIN: DIN V 18599 – Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung. Beuth-Verlag GmbH, Berlin, Dezember 2011

[6] BBR / Bundesamt für Bauwesen und Raumordnung (Hg.) (2013): Erarbeitung eines computergestützten Sanierungsratgebers für Beleuchtungsanlagen im Zweckbau basierend auf einer Sammlung technischer, energetischer und wirtschaftlicher Kennwerte typischer Bestandsanlagen und Sanierungslösungen. Fraunhofer IRB Verlag, 2013

Capturing Daylight: Transforming Office Buildings toward Advanced Lighting Controls

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Abstract

Lighting in commercial buildings has tremendous potential for energy, peak electric demand, and carbon emissions reductions. A large portion of commercial building energy use can be reduced through advanced controls that take full advantage of available daylight, and with system tuning that provides only the lighting levels actually needed by the occupants in the space.

In 2009, New York City passed the "Greener, Greater Buildings Plan (GGBP)," a comprehensive package of building energy efficiency policies, and a major element of the City's goal of a 30% reduction in greenhouse gas emissions by 2030. A key component of the GGBP is the Lighting Upgrade & Sub-metering Law (Local Law-88), requiring all large nonresidential buildings to upgrade their lighting to meet code by 2025. New York City's Local Law-88 creates an unprecedented opportunity for market transformation on a massive scale. In the coming decade, New York City, by far the largest office building market in the United States, will turnover the entire stock of lighting equipment and systems in well over 50 million square meters of office space. Over half of this floor area has good daylight availability due to the vintage of construction and prevalence of glass facades. The New York City legislation provides a once in a generation opportunity to encourage building owners and managers to go beyond code and realize the potential for substantial energy savings and peak demand reduction.

Our analysis indicates that at least 10.6 million square meters of New York City office space is conducive to the installation of daylighting controls and that retrofitting these spaces would result in electric demand reduction of 160 megawatts, and 340 gigawatt hours (gWh) of electricity savings. We estimate this would result in an annual financial savings of over US$70 million for New York City building owners and tenants.

In order to understand the potential for advanced lighting controls, Green Light New York launched a multi-stakeholder project which examined the energy and demand savings potential from using "state of the shelf" lighting controls systems, including dimming ballasts and daylight sensors, to take advantage of both demand response and daylighting control; and presented a multi-year market transformation plan to capture the maximum energy and peak demand savings. This paper presents the results of this study along with an early progress report on the market transformation plan that has been initiated to capture the maximum savings from this ambitious regulatory policy.

The Opportunity

Introduction

Lighting New York City's office buildings consumes a tremendous amount of energy - more than any other electrical end use – accounting for nearly one third of Con Edison's (the local utility) commercial sector electricity delivery.[1] In late 2009, New York City passed a suite of laws called the "Greener, Greater Buildings Plan," as part of a host of measures intended to reduce energy demand and greenhouse gas emissions.

One of these new laws created a New York City Energy Conservation Construction Code- eliminating a previous loophole that exempted lighting upgrades (and other work) from meeting current energy

[1] The reference forecast presented in Con Edison's Energy Efficiency Potential Study shows interior lighting consuming 26%, and exterior lighting 6%, of the company's 2007 commercial electricity consumption (Energy Efficiency Potential Study for Consolidated Edison Company of New York, Inc.; Volume 2: Electric Potential Report, Global Energy Partners, LLC, Walnut Creek, March 2010).

efficiency requirements. Two other laws, the benchmarking and the retro-commissioning laws, are driving building energy awareness and transparency, and proving powerful motivators toward action. The Benchmarking Law (Local Law-84 of 2009) requires all buildings over 4,650 square meters to annual benchmark their energy and water usage, making the site and building Energy Use Intensity data and Energy Star ratings public. The Energy Audits and Retro-commissioning Law (Local Law-87 of 2009) requires this same set of New York City buildings to perform an energy audit every ten years, tune up the building systems, and identify energy efficiency retrofit projects that have a reasonable payback period. A fourth law, the Lighting & Sub-metering law (Local Law 88 of 2009), requires all large non-residential buildings to upgrade their lighting systems by 2025 to meet the current NYC Energy Conservation Construction Code in place at the time of the upgrade.

The lighting upgrade requirement is estimated to affect 116 million square meters of space and represents a singular opportunity to drive substantial energy savings, including peak demand reductions. The lighting industry has seen unprecedented innovations over the last 25 years, including multiple new technologies and a far more nuanced understanding of the appropriate types and amount of lighting for different uses. Due to the code exemptions noted above, New York City's building stock has not fully benefited from these improvements. Significant reductions in the typical connected lighting load are available, and better controls are cutting the number of hours that electric lights are turned on and reducing the energy that lights consume when they are in use.

Daylighting is an important component of a comprehensive lighting controls package. Energy savings from daylighting are only realized if controls make it easy and acceptable to turn down or dim the electric lighting in the space. Additionally, the interaction of the lighting with window shades and blinds, and with the colors of interior finishes, has the potential to negatively impact occupant satisfaction if not managed properly. Daylighting in buildings can save significant electricity, including reducing peak demand, while also enhancing occupant satisfaction in the building.

New York City buildings are very well situated to capitalize on the benefits of daylight. Many of the City's older office buildings were designed to utilize daylight, as they were built in electric lighting's infancy. Block sizes and orientation have generally resulted in pre-war building floor plates in which daylight reaches a good portion of the floor area – in fact, New York City's first comprehensive zoning ordinance was enacted in 1916 in part to preserve access to daylight. Apparently, building owners accepted the 1916 zoning changes in part because they understood that daylit offices could command higher rent.

The City's recently adopted lighting upgrade law will drive massive retrofits of antiquated (mostly non code compliant) lighting systems throughout larger office buildings, dramatically reducing lighting energy use. This wave of forth-coming lighting retrofits in New York City is a unique opportunity to maximize potential energy savings and the quality of our indoor environments.

New York City's Office Market

New York City has a unique concentration of office buildings – the biggest office market in the United States by a significant margin. A 2002 report found that New York City "… is far and away the largest single concentration of office activity in the nation. New York City by itself has approximately ten percent of the entire stock of offices in the United States; a remarkable statistic as the city accounts for just 2.8 % of the national population and employment."[2]

The same report went on to state, "Manhattan is far and away the largest single market in the nation (and in the world), with about twice the inventory of the next largest areas– Washington, DC, Chicago and Los Angeles… Lower Manhattan, taken by itself, represents an office inventory equal to such metro areas as Boston, Dallas and Atlanta."

Another way to view the size of the New York City office market relative to other cities is comparing the amount of office space in city Central Business Districts, as shown below.

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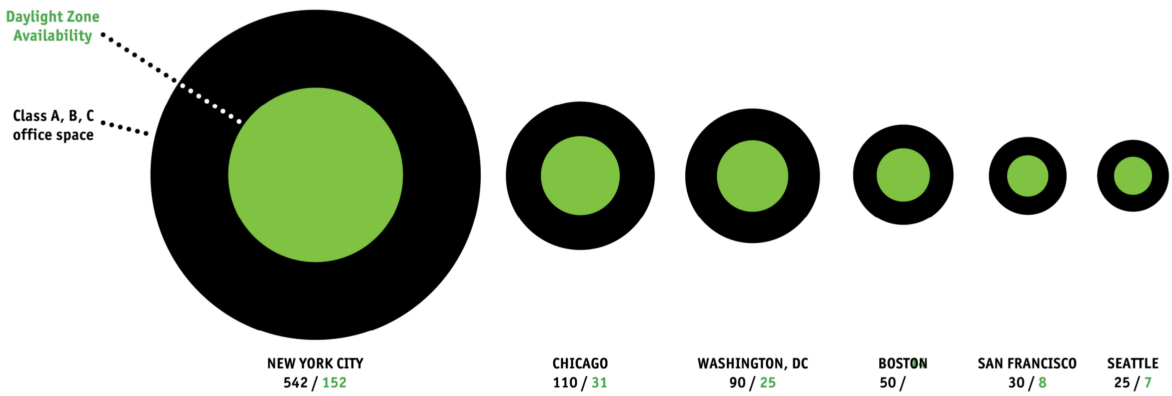
[2] The New York Regional and Downtown Office Market: History and Prospects after 9/11. Report prepared for the Civic Alliance, August 9, 2002, by Hugh F. Kelly.

OFFICE SPACE IN MAJOR U.S. CENTRAL
BUSINESS DISTRICTS (MILLION SQ. FT)



Note: 100 million square feet (sq.ft.) is approximately 9.3 million square meters

Source: Data for office markets outside of NYC from US Office Market Report, March 2012, prepared by Flacon Real Estate Investment Management, Ltd. ("Daylight Zone Availability" discussed in Technical Potential section, below).

44% of New York City's current office building stock was constructed prior to 1950, a period in which buildings were typically reliant on daylight *and* natural ventilation and therefore included numerous features to enable this, including:

- Narrow floor plates, light wells and courtyards;
- Windows in nearly every space, including storage and toilet rooms;
- Transom windows and interior glazing to communicate daylight into internal hallways.

Nearly half the office buildings impacted by New York City's lighting retrofit legislation will typically include basic features that are highly conducive to the application of sophisticated daylighting systems.

Another third of New York City office buildings were constructed between 1950 and 1980, an era defined by:

- Inexpensive energy;
- The onset of widely available air conditioning systems;
- Lighting standards that assumed high illuminance values would improve occupant comfort;
- A widespread belief in sealed office environments intentionally disconnected from the natural environment.

These factors resulted in designs that largely ignore access to daylight and provide only rudimentary lighting controls (whole floor switching inaccessible to the occupants, for instance, was the norm).

The scale of New York City's office market, and the onset of legislation requiring broad retrofits of lighting, presents an unprecedented opportunity to drive market transformation of lighting control systems. Upgrading the electric lighting systems in large New York City buildings is already attracting the attention of lighting equipment manufacturers, who see this as a key opportunity to demonstrate the quick payback of investments in efficient lighting and to support broader building efficiency goals and peak demand targets.

New York City Large Office Buildings (greater than 4,650 square meters)

				Class of space (thousand m^2)		
	Total Area (Km^2)	**No. of buildings**	**Average Size (Km^2)**	**Class A**	**Class B**	**Class C**
Downtown	9,662	444	22.6	6,782	2,508	372
Midtown	27,221	1,531	18.5	19,324	5,853	2,044
Midtown South	7,804	1,203	7.7	1,301	4,274	2,232
Uptown	743	332	3.6	185	372	279
Manhattan Total	***45,430***	***3,510***		***27,592***	***13,006***	***5,017***
Other Boroughs	***4,924***					
NYC Total	***50,354***					

Source: Commercial Real Estate Market Report, prepared for the New York State Energy Research & Development Authority by HR&A Advisors. Summer 2010.

Emulating Success

As a global leader, New York City can help set precedents and lead by example. Several projects are underway throughout the United States that follow New York City's example of combining legislation and motivation to transform its building stock to capture energy and carbon reductions. The Natural Resources Defense Council, in collaboration with the Institute for Market Transformation, recently launched the new City Energy Project. Partnering with ten major US Cities, the project will emulate the success of New York's Greener Greater Buildings Plan. Projections for the project's effects are dramatically reduced building energy use, less pollution, and saving residents and businesses a combined $1 billion a year in energy costs; and it is projected to cut a combined total of 5 million to 7 million tons of carbon emissions annually.[3]

Additionally, New York City has been a major participant in the C40 Large Cities Climate Leadership Group, where the largest cities in the world have gathered to share experiences and compare policy best practices. Many other cities around the world are looking at New York City initiatives as a model for implementation. Much of what has been adopted in New York City relatively quickly spreads around the world.

Understanding the Potential

Interior lighting energy accounts for 26% of New York City office building electricity use[4]. Electricity for larger buildings is billed for two quantities: the amount of electricity consumed ("energy" used, measured in kilowatt-hours, or kWh), and the "peak" demand (expressed as kilowatts, or kW) set in any given billing period. For most customers, "peak demand" is the highest amount of kW used during any 30 minute period in a given month, and for a large number of NYC office customers the highest demand set in any month is carried as the per kW charge for the full year. This "ratchet" mechanism gives customers strong incentive to keep their electric load relatively flat and consistently low throughout the year. As such, "peak demand" is perhaps the single most important determinant of a building's electricity charges. Energy providers charge for peak demand levels because they are required by regulatory mandate to be able to supply that amount any time a customer may use it; as a result peak capacity is a major cost driver of current utility rates. Peak periods are when all available generating equipment needs to run, including the oldest, least efficient, and dirtiest power plants feeding the grid, so reducing peak load has significant environmental benefits.

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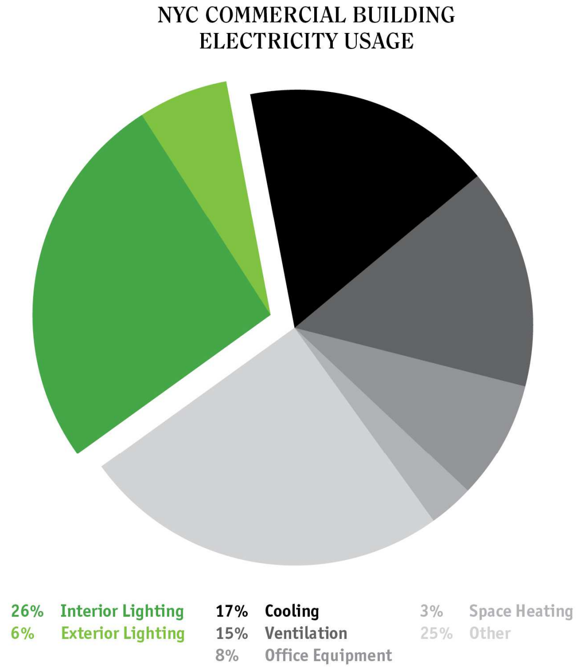
[3] Natural Resources Defense Council, Environmental News Media Center, Press Release. January 29, 2014. http://www.nrdc.org/media/2014/140129a.asp. See also: http://www.cityenergyproject.org.

[4] Energy Efficiency Potential Study for Consolidated Edison of New York, Inc., as described in Note 1. Additional information provided by Con Edison specific to large office buildings confirmed the same 26% of total use for interior lighting.



Source: Con Edison 2010 Energy Efficiency Potential Study (see endnote 1)

Daylight is most available at the time of day when demand for electricity is highest, and when the electricity is most expensive; in New York City this is a summer afternoon, when the warmest hours of the day occur, occupants and equipment have been shedding heat most of the day, and therefore air conditioning demand is highest. And daylight is most available in summer, the season with highest peak electricity use. Daylight design has strong potential to not just reduce overall energy use, but to substantially reduce demand during peak periods. With this in mind, daylighting should be a priority of both the consumers and providers of electricity.

Reducing lighting use can also reduce the need for air-conditioning if solar gain is managed carefully at the windows. Even the most efficient lighting sources contribute to “internal gains” because even efficient lamps convert only a fraction of the electricity into useful light, with the remainder emitted as heat. In many office buildings, internal gains are the primary driver of air conditioning needs for significant portions of the year. These internal gains include heat from lighting, but also body heat from occupants, and heat from equipment like computers and printers. In many cases these internal loads are great enough that the office building will require cooling even in winter. Cutting internal gains from electric lighting use can have significant impacts on energy use, with the most dramatic financial impact obviously occurring during peak periods.

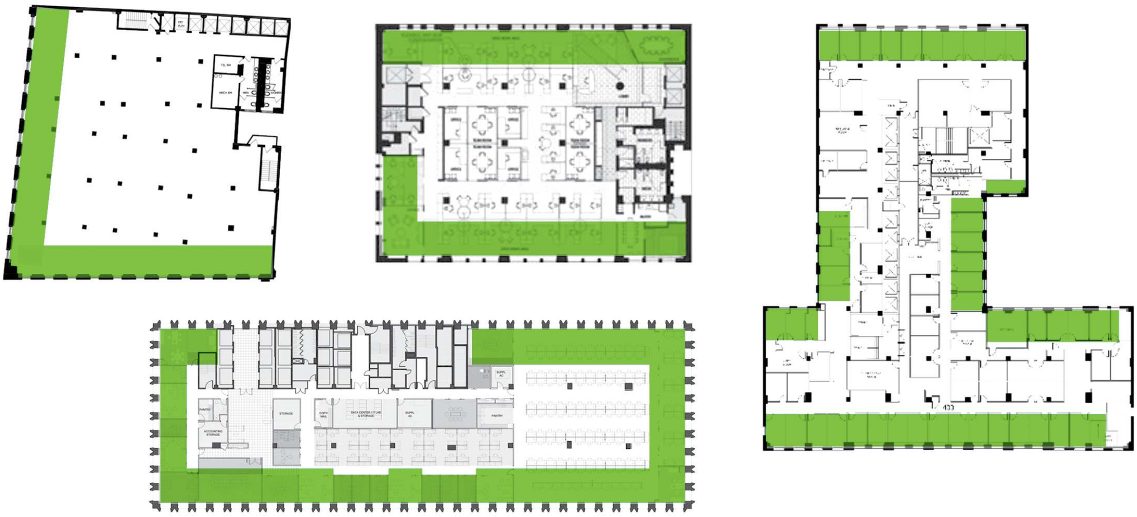
Technical Potential

To estimate the energy use and peak demand reduction potential that would result from the retrofitting of advanced daylighting controls in New York City office buildings a simple model has been developed. The model uses the office building floor area estimates described above, along with information about current lighting energy use from studies prepared for Con Edison. More information about the model can be found in the full Green Light New York report: Let There Be Daylight.[5]

Thirty New York City office buildings – a representative sample including typical size, vintage and building envelope/glazing styles - were analyzed to understand typical floor plan layouts and daylight availability in the building stock. Each building in the data set is larger than 4,650 square meters, and is therefore among the pool of buildings that will be required by recent legislation to upgrade their lighting to current code by 2025. From this analysis, the “daylight zone area” (DZA) was established: the area where electric lighting could be significantly reduced or turned off. The DZA includes spaces within 4.6 meters of the building perimeter where there is an exterior wall with windows. This zone is reduced to the depth of any private offices that might be along the exterior walls. The DZA for four example buildings is shown below.

[5] Let There Be Daylight, published by Green Light New York, December 2012, available at www.greenlightny.org

DAYLIGHT ZONE AREAS
FOR EXAMPLE BUILDINGS



Source: Green Light New York analysis of typical commercial building floor plates

After studying the floor plates of these typical buildings, the average DZA for all of the buildings was found to be roughly 28% of the whole building floor area. This fraction, when multiplied by the 50 million square meters of large office space in all five boroughs, results in potential floor area for daylighting controls of about 14 million square meters.

This potential floor area was further reduced because there are other factors that will limit the daylight availability in some offices. Filters were developed such as physical factors, including façade factors (window to wall area ratio, transmittance of glass), and weather factors like sun availability. Certain occupancy filters were also assumed, including space use, occupancy type, and configuration of interiors (perimeter offices); each of which would reduce the available space for daylighting retrofits. These adjustments conservatively reduce the potential space by another 25%, bringing the total floor area where daylighting controls might be deployed down to 10.6 million square meters.

While many studies have shown that electric lighting can be completely turned off at the perimeter for extensive periods of the day, for this analysis it was assumed that some electric lighting would remain on in the DZA, though at a reduced lighting power density of 4 watts per m^2 during peak load periods (relative to the current assumed average of 18.1 W/m^2). Our analysis also assumes that the electric lighting load varies throughout the year, with more lighting required (and therefore more electricity drawn) in winter than summer, as well as throughout each day, with more lighting required in mornings and late afternoons.

These measures result in a reduction of lighting energy use from the current average of 51kWh/m2/year to 21 kWh/m2/year.

The resulting energy savings from reducing the lighting power density from 18 to 4 watts per m2, and the annual electricity consumption from 51 to 21 kWh/m2/year, over the 10.6 million square meters of daylight available floor area, results in potential savings of 160 MW of electric demand, and 340 gigawatt hours (gWh) of electricity savings.

Using the average electricity charge for New York City commercial buildings, this electricity reduction is equal to over US$70 million in annual savings for New York City owners and tenants.

As noted earlier, reductions in lighting energy use also result in lower internal loads and reduced demand for air conditioning, resulting in further peak demand reduction. This savings was factored into this analysis.

Economic Potential

While the technical potential for energy and cost savings for daylighting controls is large, tapping them immediately is challenging due to significant cost barriers and the lack of widespread experience with the use of these systems. Dimmable ballasts and advanced lighting controls remain expensive relative to simple, code compliant systems, and the labor costs of retrofitting these systems is relatively high, resulting in a longer return on investment than most projects are willing or able to consider.

Currently, it is estimated that a comprehensive advanced daylighting controls retrofit has a payback in the range of 5 to 10 years – a longer cost recovery period than most owners or tenants in the United States will find acceptable. However, given the scale of lighting retrofits that will be taking place in the coming decade, it is realistic to expect both equipment and labor costs will decline. Additionally, digital controls and wireless systems (where sensors, controls, and fixtures communicate without the need for the expensive installation of control wiring) are reducing overall installation costs significantly. A well-designed incentive program could ensure these systems are cost-effective almost immediately.

While a number of demonstration projects are getting underway in late 2013 and early 2014, it is unlikely that any large-scale retrofit initiative could be launched prior to 2015. A targeted effort to retrofit advanced daylight controls in 3% of New York City office space annually for three years, and 5% of office space annually for the next three years, would result in 38 MW of demand reduction by 2020, with resulting annual energy savings of 82 gigawatt hours, worth about US$16 million in reduced electric bills to customers at 2011 average commercial rates.

Summary

The density of NYC office space in a compact geographical area, with a relatively small group of owners, managers and tenants controlling a large portion of that space, combined with a regulatory mandate to retrofit the lighting in that space, creates a unique opportunity to guide and transform the market for optimal lighting control packages. Additionally, NYC has a unique concentration of Real Estate professionals -- designers, engineers, owners, operators, and managers – who operate on a global scale. This provides the opportunity for a market transformation reaching well beyond the boarders of New York City. While there are a range of technologies that can reduce lighting energy use, advanced daylighting systems are an important and unique tool toward maximizing energy savings, with a host of important collateral benefits: peak demand reduction, lower utility bills (from both reduced energy use and reductions in peak demand charges), effective integration in demand response initiatives, and improved occupant health and satisfaction.

The scale of the New York City opportunity, with all large, non-residential buildings required to retrofit their lighting by 2025 (only 11 years at the writing of this report), is an opportunity to drive massive sales of dimmable ballasts and improved controls. The advent of wireless control technology is another significant potential benefit to the controls retrofit market. Wireless technology allows a much lower cost installation and implementation of daylight sensors and controls, augmenting the capability of existing systems without requiring a complete redesign or total system replacement, and avoiding the separate controls wiring typically required.

A creative procurement competition and/or incentive program could transform the ballast and wireless control markets, ensuring costs are competitive with traditional systems.

BARRIERS

Complicated systems

The potential energy savings from daylight controls has been recognized for a long time, but there are limited success stories that demonstrate significant realized savings. In the late 1970s, the US Department of Energy's Energy Efficient Lighting Program set out to demonstrate the energy savings and cost-effectiveness of advanced daylight controls; large potential savings were found. However, many of the barriers identified over 30 years ago remain today, and little of the potential savings has yet to be harvested.

Unfortunately, doing daylighting right is not easy. There are interactions with interior shades and blinds to consider- often deployed to prevent screen glare or reflected glare from neighboring glass buildings. In many cases, there is too much natural light available, so shades and blinds must be adjusted regularly throughout the day – a major challenge when these adjustments affect multiple workers in open office areas and blinds are likely to be drawn down at the first hint of glare and never raised again.

Integrating the controls for the electric lighting with information about available light levels in the space can also be challenging. While designers often know how to do this well, educating the occupants in the building about the systems rarely occurs, and often control systems are quickly bypassed because they are perceived as challenging to use, or not providing the quality of light that occupants desire.

While it is easy to measure light levels provided by electric lighting, the quality of daylight in a space is harder to quantify. A great deal of work has been done in recent years attempting to develop "daylight metrics" – indicators of performance about the use of daylight and occupant satisfaction, but there are not yet widely accepted, simple to use metrics for this purpose. And all daylight is not created equal. The uniform blue skylight of the clear northern sky is relatively easy to accommodate and control, while direct sunlight (especially the low angled sun of morning and late afternoon/summer evening) can be very challenging in terms of both visual and thermal comfort.

For advanced daylighting systems to work optimally some integration with shading systems is almost always required. Furthermore, optimal lighting design requires coordination with interior design and finishes. The color of carpets, walls and furnishings, the height and transparency of interior partitions, and other attributes, can dramatically affect the resulting light levels and the ability of daylight to adequately serve the space. Unfortunately, in most cases these interior finish decisions are made with little regard for their impact on the lighting systems, whether the project intends to utilize daylight or not.

Proper commissioning of advanced daylighting systems is also critical, as is continued maintenance and training. Building operators and occupants (if they will need to interface with the system) need to understand the intended operation of the systems and building managers need to know how to keep them functioning properly. Because these systems are not commonplace, in most cases the fairly extensive training and guidance required does not occur.

After publishing a feature story in 2012 on "Doing Daylighting Right," Environmental Building News[6] published a very informative piece: "More Heat Than Light: Six Wrong Ways to Daylight a Building". The six "wrong ways" identified were:

- Overglaze it
- Ignore orientation
- Emphasize views and call it daylighting anyway
- Skip the automated controls (or skimp on commissioning)
- Bump up the contrast, and
- Keep occupants out of the loop.

At least some of these problems seem to be common among a number of recent NYC daylight retrofit projects. Unfortunately, many existing projects with advanced daylighting systems are not working as intended, or have been disabled. In our research for this report, discussions with a wide variety of practitioners had a common theme: well-intentioned daylighting systems that are not delivering expected savings. The most commonly cited reasons for these failures are "value-engineering" cost cutting measures, including last minute reductions in the number of daylight sensors.

Surprisingly, several of these poorly functioning examples are projects that have been the subject of widely disseminated daylighting system case studies, and which include occupants that seem relatively motivated to get the systems working properly. As a result, designs that are not functioning

[6] Doing Daylighting Right, Feature Story in Environmental Building News, March 2012 issue. Full article only accessible with subscription, but the "Six Wrong Ways to Daylight a Building" is available to all at http://www2.buildinggreen.com/blogs/more-heat-light-six-wrong-ways-daylight-building

properly are being hailed as exemplars without acknowledgement of occupancy phase issues. The problems encountered may or may not be the result of design phase decision-making but it is clear there is a need for more forensic investigation of why these projects are not operating and delivering anticipated savings. Not enough information is currently known about why some projects are not working as expected. However, researchers and experienced industry leaders are confident that these challenges can be overcome through carefully organized analysis and training.

Expensive components

Daylight controls usually supplement simpler, lower cost lighting controls, such as occupancy/vacancy sensors, and more flexible circuiting and switching which allow certain spaces to shut off lights, or reduce levels. These lower cost lighting controls, when applied to more efficient, lower overall wattage lighting systems, provide a significant majority of available energy efficiency measures. Daylighting controls supplement these lower cost systems but if considered independently and added after the other systems are in place they have long payback periods. A key challenge remains the dimmable ballast used in fluorescent systems- these are still low volume, high cost elements in the lighting industry.

To defray these higher dimming ballast costs many projects around the country have installed either “on/off” or less expensive “stepped” daylighting systems that switch lights or lamps fully on or off (sometimes set levels of the light output) in response to available daylight. This may work in certain public spaces (hallways, lobbies, etc.) but our research indicates it is generally not acceptable to users in active workspaces. Surveys have repeatedly found that most building occupants are dissatisfied with the lighting when it goes on and off regularly while they are in the space. Without the continuously dimming ballasts offered in advanced daylighting systems it is very likely that the controls will be disabled. To ensure long-term functionality, dimming control is a necessary component of a daylighting system.

Dimmable ballasts are a significant portion of the cost of an advanced daylighting system, but are required to enable many of the capabilities of such a system mentioned in this study, including participation in demand response programs, and tuning light levels in response to specific activities. These capabilities are critical to capture all potential savings from lighting efficiency.

Designing and operating daylighting controls correctly requires skill, attention and diligent follow up. Even well-designed projects are often subjected to “value-engineering” cost cutting that impairs the functionality of the system. Case studies of daylighting-enabled office buildings with extensive monitoring in the occupancy phase are needed to demonstrate actual energy and cost savings. These studies should especially focus on delivering energy savings, peak demand reductions and occupant satisfaction.

Dimmable ballasts and daylight sensors are expensive today because they have never been engineered as high volume, low cost systems. Historically, sophisticated dimmable systems were installed as low volume solutions in spaces where budgets were not critical drivers, such as executive conference rooms. Making dimmable ballasts the default solution for virtually all office lighting would almost certainly drive innovation and competition among manufacturers in response to new market opportunities.

Discussions with suppliers suggest that dimmable ballasts could be manufactured in large volume at a $5 premium rather than the $20–60 per ballast cost often quoted today. Likewise, improved sensors and wireless communications will further reduce the networking and communications costs involved in making these systems work effectively. A major incentive program in New York City has the potential to drive costs down substantially, due to both the volume of potential work in this region and because the New York City design, real estate and lighting communities impact work all over the world.

THE MARKET TRANSFORMATION PLAN

Green Light New York has embarked on a comprehensive, three-stage, six-year implementation plan with the following primary elements: proof of concept projects; financial incentives; training and outreach; and deployment, evaluation and reporting. At the end of this carefully incentivized deployment period its is estimated that dimmable ballasts and related controls will be competitive enough with standard systems that they can be mandated by code to deliver significant demand response potential and energy use savings.

Although financial incentives and training are critical components to widespread deployment, this paper's focus is on the proof of concept demonstration projects, the first phase of the proposed market transformation plan.

Proof of Concept

There is a strong need for well-documented demonstration projects that provide the "proof of concept" for advanced daylighting systems. These projects should focus on reducing additional construction costs and increasing long term cost benefits, measured energy reductions, and energy cost savings, including an emphasis on peak demand reductions and assessing occupant response. There are many green building case studies that list daylight controls among their features, but very little evidence has been gathered about how these systems are working, or what kind of energy or cost savings are resulting (if any). Proof of concept demonstration projects will not be constructed on an accelerated timeline without targeted incentives designed specifically to produce them. Just as New York City now requires the disclosure of building energy use, these demonstration projects will contribute to broader national efforts to determine the lighting contribution to building energy use.

Green Light New York has secured funding to identify, monitor, analyze and publicize advanced daylighting demonstration projects to illustrate the value of daylight harvesting to the design, construction, real estate ownership and energy policy regulation communities. These demonstration projects will be specially designed to monitor pre- and post-retrofit energy use, pre- and post-retrofit peak demand, and will involve the collection of detailed construction cost and energy cost savings figures. The case studies will include projects from the three major construction eras outlined above (Pre-1950, 1950-1980, 1980-present) each with different façade types (masonry vs. curtain wall envelope, varied % of glazing), and each of the interior layouts described above. The performance of these demonstration projects will then be extrapolated to the broader New York City, as outlined above, to estimate the potential energy use, peak demand and cost savings available. These projects will not only provide data and feedback to support the next phases of the program but will also generate interest throughout the industry and build confidence in the systems being analyzed.

Green Light New York and its partners have launched the first round of demonstration projects, "The Living Lab," which is described in more detail in the section below; and identified several other major New York City real estate firms that are interested in participating in the proof of concept pilot project described here.

A Phased Approach

To ensure that the potential energy and financial savings described above are captured requires a well-supported plan. Change of the magnitude proposed here will not occur without the active engagement and financial support of both public and private organizations. Based on the research conducted to support this report, Green Light New York recommends a plan that will systematically address the technical and business obstacles that have stymied capturing these savings potentials for decades, but builds on the self-interest of an enlightened marketplace. The plan recognizes that these changes can best be made in stages so that continuous feedback can reinforce both the message and the recommendations of the program. The multiphase plan also recognizes that there are leaders and laggards in markets and that not all owners will move at the same pace. Green Light New York suggests the following multi-phased effort to ensure long-term, cost-effective deployment of advanced daylighting systems across the majority of New York City office space by 2025:

- Phase 1 [*underway*]: Two years (2013-14) of strategically selected, very well monitored demonstration projects to document challenges and solutions and finalize plans for Phases 2 and 3;
- Phase 2: Two years (2015-16) of carefully subsidized, performance based deployment (at least 279 thousand square meters) of advanced daylighting systems, with vendors agreeing to cost and performance targets to receive incentive funds (similar to successful "bulk procurement" or PV deployment programs);

- Phase 3: Two years (2017-18) of enhanced deployment across at least 1 million square meters with lower cost targets and other well-defined success metrics (e.g., 500 trained installers and New York City trained designers).

At the end of this carefully incentivized deployment period it is estimated that dimmable ballasts and related controls will be competitive enough with standard systems they can be mandated by code to deliver significant demand response and reduction potential.

The Living Lab Initiative

Green Light New York and its partners have launched the first phase of this proposed plan: proof-of-concept demonstration projects. The *Living Lab Demonstration Project* is a collaboration between Lawrence Berkeley National Laboratory (LBNL) and Green Light New York that explores and advances innovative, integrated lighting, daylighting and shading systems in working office environments. The team will document the metrics, economics, lessons learned, and develop resources to aid the widespread deployment and successful operation of these energy saving systems**.** To advance this important project, the US Department of Energy, the New York State Energy Research & Development Authority, and the Scherman Foundation have provided funding.

To speed adoption of advanced lighting, daylighting and shading systems the Living Lab Demonstration Project will retrofit existing offices with “state-of-the-shelf” systems and monitor their performance to better understand and communicate the factors that ensure successful deployment and operation of these systems. The team has secured the participation of two leading financial institutions, Bank of America and Goldman Sachs & Co., each of which will host “living lab” demonstration floors within their flagship New York City headquarters buildings.

The project will analyze pre-retrofit performance, will include a range of space types, and will monitor control spaces to compare and contrast the impacts of the deployed systems, including effects on the satisfaction of the occupants. The two-year project includes multiple feedback loops, allowing for periodic modifications and enhancements to the systems. In addition to significant improvements in energy use performance, the project will focus on strategic procurement processes that reduce overall implementation costs.

Each of these firms have selected a single floor of their flagship headquarters, One Bryant Park and 200 West Street respectively, to demonstrate high performance, systems-oriented solutions for lighting and daylighting that reduce energy use and improve amenity and comfort. The core scope is to refurbish each floor with modified or new lighting fixtures and control systems, daylight responsive systems and improved shading. The project may extend to include plug load control and tuning local HVAC operations.

Areas of focus will include effective, high-efficient lighting, shades, solar controls and products that extend daylight penetration, and controls for scheduling and tuning of systems that respond to occupancy, light levels and other factors. The team will consider cost effectiveness while maintaining high levels of indoor environmental quality. The projects take LBNL's groundbreaking work on shading and lighting controls at The New York Times building as their model.[7] When the most effective set of integrated solutions has been identified, Bank of America and Goldman Sachs will explore replication of these solutions on other floors and throughout their respective building portfolios.

The LBNL/GLNY team expects the Living Lab projects will transform the performance and cost expectations for advanced daylighting retrofit solutions. Successful solutions, lessons-learned and the keys to ongoing performance will be communicated by Green Light New York to the greater real estate community through virtual case studies, live instruction technical training, panel discussions, webinars and other resources.

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[7] Daylighting The New York Times Building; Evaluating Performance. Lawrence Berkeley National Lab, 2014. http://windows.lbl.gov/comm_perf/nyt_post-occupancy.html

Anticipated Outcomes

- Demonstrate lighting, daylighting, and shading systems and control strategies that achieve energy performance levels well beyond those typically achieved today;
- Push beyond standard systems for a new generation of innovative solutions that meet high performance goals;
- Demonstrate ability of innovative systems to provide greater to amenity, comfort and satisfaction in the workplace;
- Explore strategies to reduce “total cost of ownership” so solutions can be widely deployed.

Process

Dec 2013	**Solicit interest from technology providers (Request For Information, or “RFI”)**	RFI includes Performance Guidelines for proposed solutions.
March 2013	**RFI Responses Due**	Applicants provide detailed proposals.
April 2014	**Final Selection**	A variety of applicants will be selected for installation in different space types.
Spring 2014	**Procurement, Installation & Commissioning**	
Summer-Fall 2014	**Initial Monitoring & Evaluation**	Analysis of performance may call for modifications or replacement of systems. Monitoring will continue into 2015.
2015	**Outreach and Training**	Develop case studies, training and other resources based on the solutions.

CONCLUSION

The implementation of the New York City lighting retrofit laws presents an unprecedented opportunity to trigger a major shift toward advanced daylight controls as the standard system within office buildings. Not pursuing daylight savings simultaneously, with other lighting system upgrades, would be a lost opportunity of enormous scale.

The amount of high end office floor space that will have its lighting modernized in the coming decade brings an opportunity for transformation of how electric lighting is controlled in offices. A successful program to ensure deployment of advanced daylight controls will reduce energy use, reduce peak demand, provide financial savings, and contribute significantly to current and future state and city initiatives to improve our impact on climate change.

The opportunity, however, is complicated and presents several challenges. This paper has quantified the potential savings, and recommends a series of actions to ensure that New York City harvests the great potential of daylighting. At the writing of this report, the first phase of the proposed action plan is underway. Working with global financial institutions, Green Light New York and its partners have launched the first round of well-monitored demonstration projects, *The Living Labs*, to document the challenges and the solutions in the deployment of advanced lighting controls. The lessons-learned from this two-year initiative will be used as the foundation to spur further action; advocate for carefully incentivized deployment; and, subsequently, for mandated codes to deliver significant energy and carbon reductions.

Continuing its leadership role in the environmental and financial stewardship of the built environment, New York City will be able to demonstrate the potential to transform office lighting across the country and the globe.

Acknowledgements

Many individuals contributed to the thinking and content of this paper and the underlying report. The authors would like to acknowledge Yetsuh Frank, of Green Light New York, as a collaborative author of this paper and are grateful for the support of the Natural Resource Defense Council for sponsoring much of this work.

Many people their contributed time and advice to this work, especially Stephen Selkowitz, Lawrence Berkeley National Lab, and other project advisors who are listed in the full “Let There Be Daylight” report published by Green Light New York.

Distributed Intelligence for Energy Saving Smart-Lighting

Sam Woodward, Havells Sylvania Europe Ltd.

Abstract

Substantial savings in energy usage in a building can be made by controlling lighting: ensuring that a space is lit only when it is occupied, and then only with sufficient artificial light to compliment available natural light. However lighting control systems tend to require an extra level of complexity to be added to a building's infrastructure: a network of sensors, bus-wiring, central controllers and the burden of commissioning these items to achieve the desired operation and performance.

This paper presents a new, simple, method of controlling multiple lighting fixtures to achieve maximum energy-saving. These fixtures are not physically connected, and are not centrally controlled; instead they act together as a group of fixtures to ensure occupancy comfort. The technique uses wireless distributed intelligence to enable groups of fixtures to form a "hive mind" that reacts to occupancy and available natural light. This is achieved using invisible Infra-Red communication, which has significant advantages over other wireless techniques, such as radio, as it does not add to the saturation of the radio spectrum, and communication problems do not carry with them the vagaries of radio-frequency interference or interaction with building materials.

The ease-of-installation of smart-fixtures equipped with this type of sensor means that energy-saving can be achieved without requiring installers to be skilled in the art of lighting control systems, they do not have to be well-versed in low-voltage wiring, and they do not require computer skills for commissioning. This de-skilling of the lighting energy-saving process will enable the more rapid uptake of the technique to enable us to meet our Kyoto obligations.

Lighting Control Requirements

Smart-lighting is lighting that reacts to its environment and the needs of users automatically. The term "smart-lighting" may be used independently of the specific type of light-source deployed.

Lighting Controls have a dual purpose within a smart-lighting application:

a) To provide a good user experience of the lit space: to ensure that appropriate illumination is provided (through a well-designed set of luminaires that are being controlled) when it is required. The building-user's experience of the lighting controls must be a positive one. A useful design guideline in this respect is to "annoy users least"! (Examples of annoying users are timed systems that switch off when a room is still occupied, systems that have too few / insensitive sensors and plunge users into darkness, systems that are over-sensitive and light areas when they are empty (potentially annoying neighbours with light pollution), and a variety of other complaints!. An optimal user-experience of the lighting controls in a space would be for them to require no manual interaction at all, in normal use, with the controls automatically ensuring user-comfort without any effort required on the part of the user.

b) To save energy, by a variety of techniques:

- Ensuring that unoccupied spaces are not lit (known as occupancy detection)
- Making use of natural light in preference to artificial light (known as daylight harvesting)
- Ensuring that the output of luminaires is no more than is required to meet design requirements, by dimming their output, compensating for an over-lit design from brand-new lamps. (known as maintained illuminance).

In other words we need to light a space when people are using it, and not light it when they're not. We need to ensure that only as much artificial light as is required is actually deployed.

Traditional Lighting Control Approaches

There has been much previous material presented on the topic of energy saving using controls, and the necessity for controls is now enshrined in legislation and good-practice. Approaches to lighting controls have traditionally ranged from simple on/off switches, to systems that operate via a network of sensors and ballasts, enabling detection and dimming of individual fixtures, or groups of fixtures. Such systems have typically required every device in the network to be identified via an address, such that it's behavior can be configured as appropriate to its location.

Such systems typically use a central-control system to coordinate activity on that network.

Ballasts and fixtures, whilst often co-located within the same housing, often do not have a one-to-one relationship: i.e. there is often one sensor controlling a small group of fixtures, usually via the authority of the central control unit, or area-controller.

Networked systems, whilst therefore enabling the required functionality, often do so with the drawbacks of the cost of a complex infrastructure and time-consuming addressing / commissioning.

Traditional systems also have scaling considerations, which means that as a system grows in size, (as the number of controlled fixtures increases) so too does the complexity of the supporting infrastructure of network cables or communication nodes:

For example a single DALI bus can control a maximum of 64 fixtures. Therefore when there are more than 64 fixtures a second bus is required, in addition to some form of controller to coordinate the two busses. For more than 128 fixtures more controllers are required, etc.

Additional scale has traditionally resulted in increased complexity.

An Alternative Approach: Distributed Intelligence

An alternative approach is to de-centralise control, enabling smart-fixtures to become completely responsible for their own light output, by making them react to the environment around them, and to their neighbours' behaviour without needing specific direction from a central controller.

Each fixture can have a sensor integrated within it, directly controlling its ballast, to react to occupancy below it, and to regulate its output in accordance with the light levels. In itself this is nothing radically new!

Figure 1. A 600x600 Office Lighting Fixture with Integrated Sensor

However we can extend the system to take into account the behaviour of the neighbouring fixtures. This is achieved as follows:

Inspiration From the Natural World

Taking inspiration from the way in which groups of creatures, such as a school of fish, all cooperating in a community together can achieve remarkable goals in the natural world, we can recognize that a group of fixtures can utilize distributed intelligence algorithms to enable a very elegant, yet very simple, solution to the challenge of lighting a space coherently and yet efficiently.

Consider a school of fish. There is no one “central control master-fish”, and yet when viewed as a whole, the school can solve complicated “problems” together, such as navigating around obstacles or avoiding danger. Each fish is aware not only of its’ immediate environment, but it’s also aware of the actions of its neighbouring fish. It therefore continually makes small decisions based on those two simple sources of inputs. Each fish is relatively un-intelligent, but when viewed as a whole, the school is collectively very intelligent.

Figure 2. [1] A school of fish, forming an “elegant system”

Additional fish can be added to the school, or fish can be taken away, and yet the overall system requires no new information in order to carry on functioning as a whole.

Application in Lighting

The same principal can be applied to an array of lighting fixtures: enable the fixtures to share their status with their neighbours, and to react to the status of those fixtures around them, as well as using the sensor to respond to the immediate physical environment.

That way when one fixture detects occupancy it can immediately illuminate itself to a pre-set desired brightness, and can share the occupancy-information with its adjacent fixtures. Those fixtures can decide themselves how to react to this new knowledge that there is occupancy close to them (even when they've not seen it themselves).

In real terms this means that when someone walks into a room, the lighting where they are can respond brightly, but the lighting next to that can also ramp up to a dimmed level, creating a comfortable "bubble of light" around the occupant.

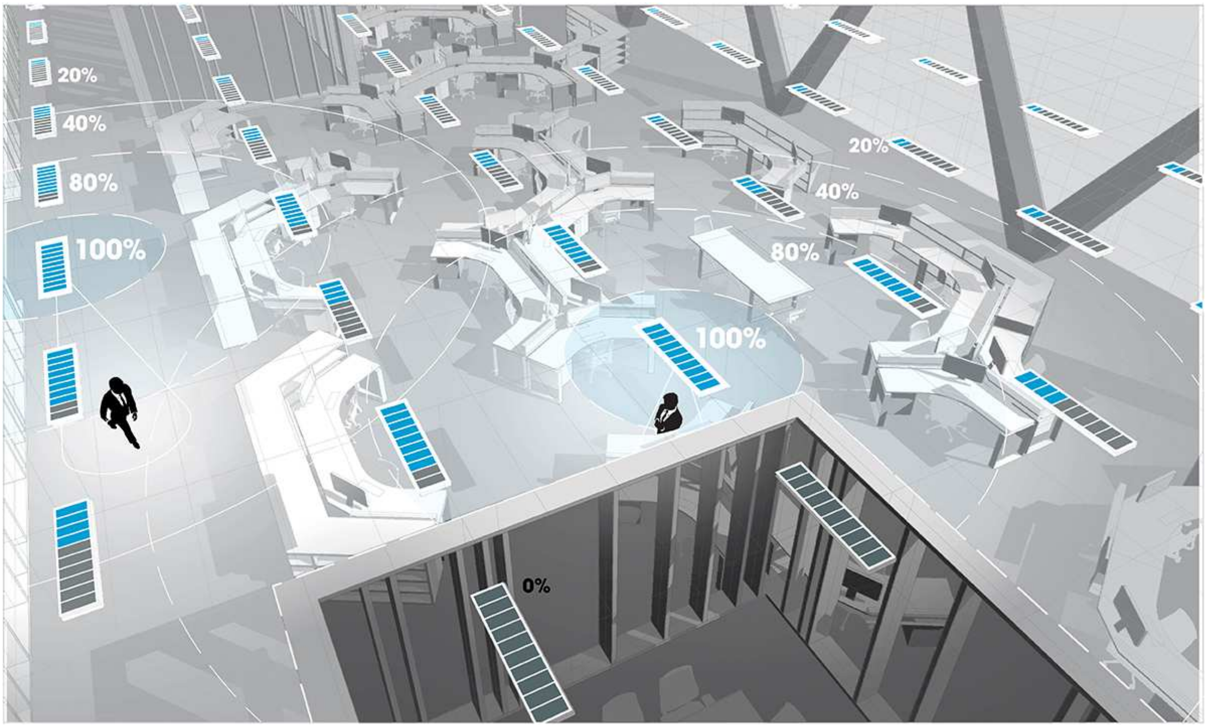

Figure 3. "Bubbles of light" around each occupant.

As the occupants move about, the "bubble of light" moves with them. As multiple occupants enter the space then multiple independent "bubbles of light" will be formed, until such a time as the whole space is lit.

Communications Between Nodes / Fixtures

One of the key requirements for a distributed-intelligence system is communication between fixtures.

Noting that one of the key drawbacks of "traditional" methods of controlling intelligent lighting is the burden of networking, the obvious option for a new method of lighting control would be wireless communication.

However, most wireless systems use radio communications. Whilst superb for some purposes, radio systems are not without their drawbacks. For example, the range (distance) of communication is hard to control, as signals may pass through walls or floors/ceilings, and therefore each node requires addressing or identification in some way to ensure that communications are only between fixtures that are relevant. Radio systems also often require considerable specialist expertise to solve the challenges of interference or spectrum-saturation.

Therefore another communication solution is to use a proximity-limited means of passing data from one fixture to another. One option to achieve this is to reflect a beam of infra-red (invisible) light onto the surface below the fixtures, to enable it to bounce into an IR receiver on the adjacent fixture. In addition to a motion sensor and ambient light-level sensor, each fixture is therefore additionally equipped with an Infra-Red transmitter and receiver, as shown in the figure below.

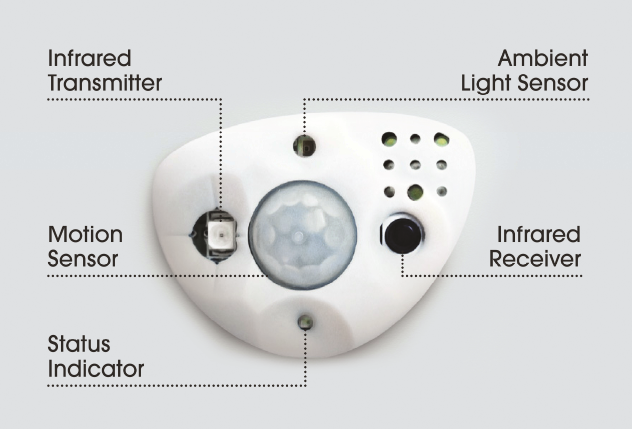

Figure 4: Sensor Array with IR Transmitter and Receiver

We use the drawback of IR communications - it being line-of-sight only - to our advantage in this specific application. Using this method, communication properties which in other applications are undesirable will in fact be beneficial:

- The communication will be limited in range
- The communication will be constrained by the walls and thus the natural geography of the space being illuminated (see figure 6).
- By using IR the communication will not be subject to the multitude of sources of radio interference

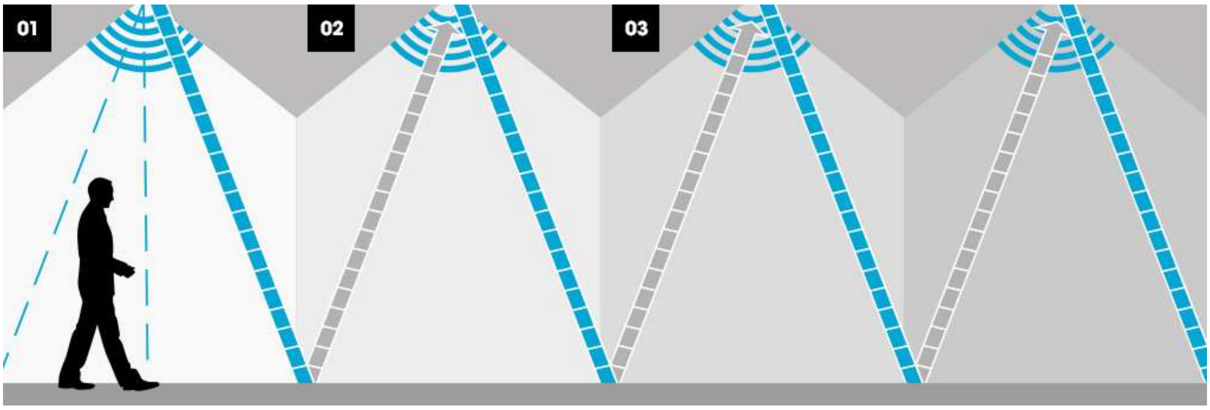

Figure 5: Transmitting Between Fixtures

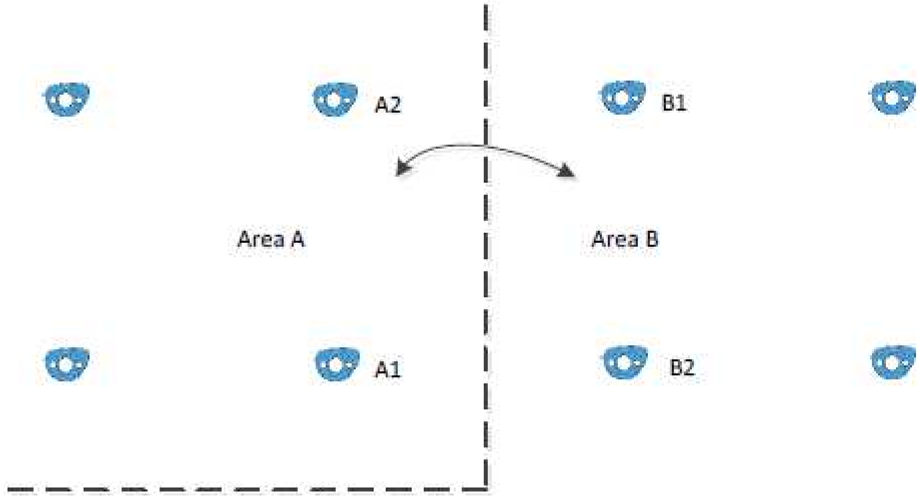

Figure 6. Communications Is Restricted To Individual Areas Using IR

Communicating Occupancy

If a fixture detects occupancy it must transmit this status, stating that it is “zero” fixtures away from the occupancy trigger event (i.e. a person is there)

When the next fixture receives a signal from an adjacent fixture it must increment the count of how many fixtures away the occupancy was detected, and re-transmit that signal, even though it has not yet seen the occupancy itself.

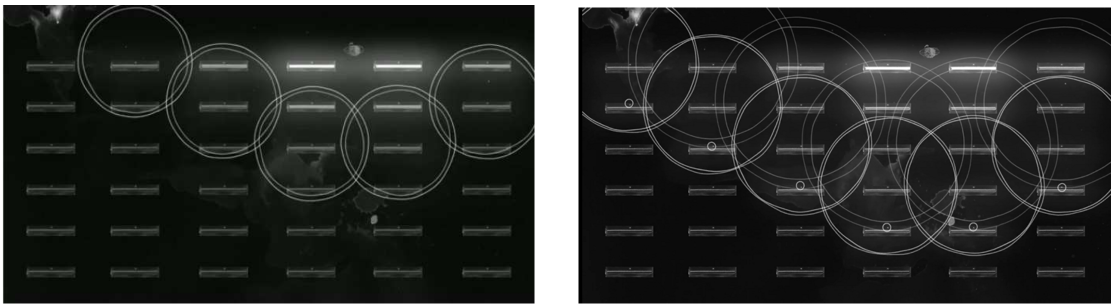

Figure 7. Propogation of Occupancy Data

This incrementing signal will propogate rapidly through the array of fixtures, so that all fixtures within the space are aware of the distance that they are from an occupant. They can therefore independently chose how to react to that signal.

Although the effect of this is for the fixtures to react as if they were one system, none of them is aware of the number of neighbours it actually has, nor are they aware of the total number of fixtures. They do not need this information.

The Occupancy Information Cloud

With an array of fixtures continually sharing their occupancy-status, a virtual “cloud” of occupancy-information data is created, by means of the continual stream of IR messages being shared between the fixtures. A receiver device, placed at any point in the “cloud” can collect IR messages and thereby know how far away it is from occupancy.

An IR receiver can “tap into” this cloud, to extract rich, real-time, data about the occupancy status of a space.

Further Applications

Using the lighting fixtures as the host for an array of detectors, and using the system described above to ensure that the whole room’s occupancy status is continually communicated, forming the Occupancy Information Cloud, we can use that data for other building systems, including HVAC, security, power-control (e.g. down-powering PC monitors or other peripherals).

Fixture Behaviour Customisation

Each fixture’s behaviour is preset with a default set of parameters, known as its “personality”. This is a a pre-defined set of responses according to the sensor and neighbour inputs including:

- The dwell time after motion is sensed
- The target light level to be achieved (as a mixture of artificial and natural light) when illumination is required
- A table of light-level values vs distance from an occupancy event (i.e. when a neighbouring fixture has detected occupancy, or is onwards-reporting that its neighbour has, but this fixture is in a currently-unoccupied area)
- A minimum light-level, when there is no occupancy

Benefits

The distributed-intelligence model presents benefits at all phases of the project: planning, installation, commissioning and use.

Energy Saving Benefits

The use of a sensor in every independent fixture means that this system has a higher density of sensors than traditional approaches. This means that the resolution of energy saving possibilities is higher: rather than controlling groups of lights, where in fact only one may *need* to be illuminated, individual fixtures, or small dynamic clusters of fixtures, can now be illuminated.

Real-world results from sites where this system has been installed have reported savings of up to 90%, compared with un-controlled installations.

Comparison with timer-switched systems also shows a clear advantage:

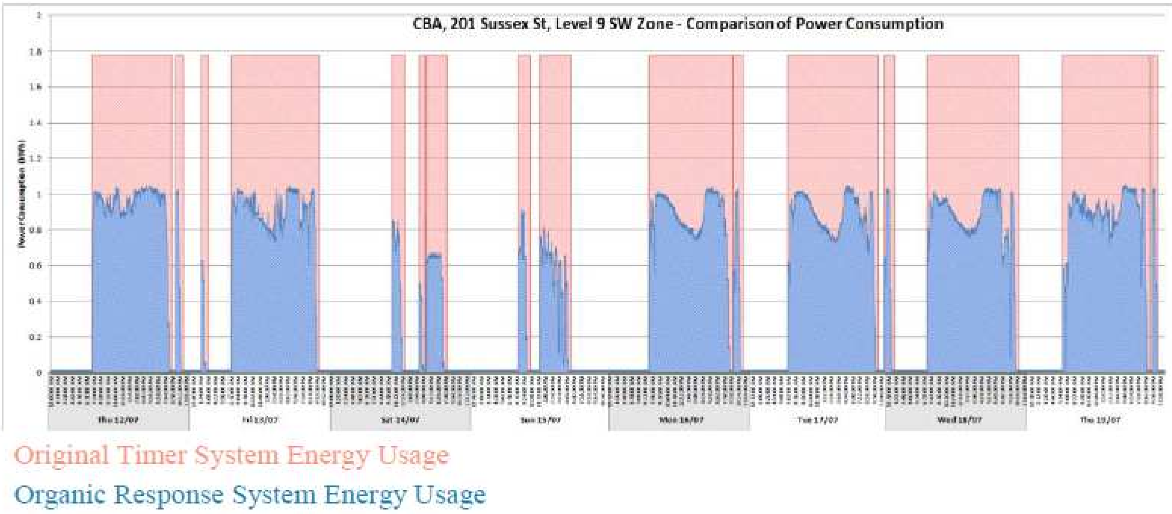

Figure 8. Comparison of Timed Control and Distributed-Intelligence System: Saving 55% [2]

Note: x-axis show dates

User Benefits

The system provides increased comfort for users of the building. Areas are illuminated in dynamic "bubbles of light" (an approach which is impractical with most centrally-controlled networked systems due to the changing nature of the "zone" requirements as people move around the space).

Although it's not a *requirement* of system set-up, it's possible to optimize the behavior of each fixture to suit the tastes of the occupants of the space. So, for example, any or each fixtures can be given an individual "maximum target light level", optimized for the "taste" of the person normally sat beneath it. This can be achieved by changing the personality-parameters of a fixture's smart-sensor without requiring any central-control node to be changed.

The user's common complaints from occupancy-detection systems can also be eliminated. With an array of sensors that is equal in density to the array of fixtures, there is a greater probability that a user will always be detected by at least one sensor, and usually by more than one. With fixtures sharing their occupancy data this gives much finer-grained coverage of sensors.

Project Benefits

A wireless distributed-intelligence system, as described above, presents many benefits to the project, from conception to completion:

Materials cost (reduced copper) – at least 40% of the wiring normally associated with a hard-wired networked system is removed. Instead of wiring fixtures with Live+Neutral+Earth and a DATA pair, in this example only the mains wiring is required.

Installation Time Saving – reduced wiring reduces installation time.

Diagnostic and de-bugging saving – eliminating the data cabling removes the area of a project which has historically led to the most time spent on fauly-finding.

Project management cost – all of the reduction in wiring also reduces project-management time required for planning the same.

Summary

There are multiple ways of solving the challenge of controlling the lighting in a space.

Many take an every-more complex approach to control, with layers of bus wiring, networking infrastructure and the burden of addressing/commissioning. As scale increases so does complexity.

The technique presented in this paper shows the opposite approach: enabling an array of simple-to-install fixtures, which require no individual addressing, to operate as a “hive mind”; each member of the array responding to its environment and its neighbours.

References

[1] Image of school of fish, protecting against preadators. Creative Commons, source: Flickr. Credis: Adam Rifkin

[2] Leung, Carter. Arup. “Organic Response. Level 9 Darling Park Demo Site, Report”. September 2012. Accessed via www.organicresponse.com.au

Conditional Demand Analysis of Commercial Electrical Energy Consumption

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Abstract

Electric utilities require accurate estimates of end-use energy consumption for power system planning, load forecasting, marketing and demand-side management. End-use consumption in the commercial sector refers to the consumption of space heating and cooling, air distribution, water heating, lighting and other specific uses. This report presents the methodology and results of a commercial end-use study for British Columbia, Canada. This study used Conditional Demand Analysis (CDA) to estimate Unit Energy Consumption (UEC) values for the main commercial end-uses. The study generated UEC estimates for nine end-uses based on a sample of 1,126 commercial customers. Sixty-two months of billing data were used. UECs were calculated for each customer possessing the end-use by substituting customer variables into the end-use equations. Normal heating degree days and cooling degree days were substituted to generate weather-normalized UECs for space heating/cooling and water heating. The results were then weighted to the population of all commercial sector customers. Weighted average total end use consumption levels were calculated across all customers possessing the end-use and across the various customer subgroups. Average total annual end use consumption levels were as follows: lighting 221,000 kWh; air distribution 228,000 kWh; primary electric space heating 110,000 kWh; secondary electric space heating 10,000 kWh; space cooling 69,000 kWh; and water heating 38,000 kWh.

Introduction

Accurate information on electricity consumption by end use is critical in planning, implementing and evaluating initiatives to improve energy use in commercial and institutional buildings. The purpose of this study is to provide the results of a detailed CDA analysis conducted for commercial and institutional buildings in British Columbia. The objectives of this study were to first estimate UEC values for nine commercial end-uses, then by seven building types (Table 1).

Table 1: UEC Estimates: end uses and building types

End Uses	Main space heating, Secondary space heating, Air distribution, Refrigerator, Cooking, Space cooling, Lighting, Water heating, Office equipment
Building Types	Office, Restaurant, Retail, Public Assembly, Education, Health Care, Lodging.

Three main methods have been established for estimating end use electricity consumption: end use metering, calibrated engineering simulations, and conditional demand analysis (CDA). CDA has been widely used in the residential sector [1], but there are few examples of commercial CDA analysis.

CDA is a multivariate regression technique which combines utility billing data with weather information and customer survey data. CDA starts with the concept that the total building load can be disaggregated into various end use loads which can be modelled statistically. The basic idea of the CDA model was developed by Parti and Parti (see Lawerence and Parti [2] and Parti and Parti [3]) as a substitute for expensive end use metering for the analysis of end use consumption in residential dwellings.

A small number of studies have applied the conditional demand approach to the analysis of end use consumption in commercial buildings. Parti et al. [4] built a detailed CDA for the commercial sector.

They used the model to estimate both end use consumption and end use conservation. Ignelzi and Train [5] also applied a detailed CDA to commercial buildings. They used their model to examine energy utilization indices and the persistence of savings. Turiel et al. [6] applied CDA to a sample of 5,540 surveyed commercial buildings in the Pacific Gas and Electric service territory. They report estimated end use consumption, but they do not provide details of the regressions run to estimate these UECs.

There are several reasons for the limited number of published results on CDA for commercial buildings compared to the larger set of residential CDA (Turiel et al. [6]):

- Commercial sector buildings are more diverse than residential dwellings. There is a wide range of commercial establishments buildings, and some buildings house more than one business type;
- Commercial buildings frequently are serviced by more than one electricity meter, so the level of aggregation becomes an issue;
- Commercial buildings have a large number of appliances, and it is difficult to capture adequate quantitative data on these through a survey, and undertaking a large number of on-site audits to collect data may be prohibitively expensive.

Data and Methods

The basic idea underlying CDA is that the total load can be disaggregated into the component or end-use loads. These in turn can be modeled using thermodynamic principles and behavioural information. The regression coefficients are used to calculate unit energy consumption values for major end-uses and conservation measures.

Data

Three main data sources were used. First, information on building size, geometry, occupancy, equipment installed and fuels used came from a detailed customer survey. Information on electricity consumption came from utility files. Information on weather came from Environment Canada. Finally, limited end use metering data was used to refine the end use estimates. The data set included 1,126 of BC Hydro commercial customers who completed the 2006 or 2009 Commercial End Use Surveys. Monthly billing data for the sixty-two month period from January 2005 to February 2010 was used in the regression analysis.

The survey included detailed questions on all major commercial end-uses: space heating, space cooling, ventilation, water heating, lighting, refrigeration, freezing, office equipment, cooking and process equipment.

The survey samples were drawn from a sampling frame which included three strata: *region* (Lower Mainland, Vancouver Island, Southern Interior and North); *building type* (office, restaurant, retail, food store, warehouse, education, health care, lodging, public assembly, industrial and other); and *annual consumption*. Stratified samples were used because a simple random sample would not give adequate representation for some cells and because stratification allowed the estimation efficiency to be increased. One complicating factor in estimating a conditional demand model for the commercial sector is the heterogeneity of buildings within a given building type. The data in Table 2 illustrate this heterogeneity, summarizing the average or arithmetic mean of floor space by building type, for those observations used in the regression analysis.

Table 2: Floor Space by Building Type (square metres)

	Mean	Standard deviation
Office	6,544	11,616
Restaurant	1,060	1,753
Retail Store	1,776	6,817
Public Assembly	2,207	3,245
Education	3,657	4,182
Health Care	2,289	4,056
Lodging	5,408	8,158

Methods

The CDA method is based on the premise that the total facility consumption is the sum of consumption of various end-uses plus an error term or residual [1] [2] [3]. Appliance saturations are modeled by an indicator variable to indicate the presence or absence of an end-use in a particular facility or by a count variable to indicate the number of units present. The estimated regression coefficient is the UEC. The UECs are modeled as functions of appropriate exogenous variables. The detailed model uses a combined behavioral-thermodynamic approach. With this approach, basic thermodynamic relationships are exploited to define equations reflecting energy consumption for major end-uses, and these are modified by behavioral characteristics such as the manner and frequency with which an end-use is employed.

$$HEC_{ht} = \sum_{all\ a} UEC_{aht}\ S_{ah}$$

Here, HEC_{ht} is the total energy consumption by facility h in month t, UEC_{aht} is the energy consumption for end- use a by facility h in month t, and S_{ah} is the stock of end-use a in facility h. Stocks are represented by indicator variables to indicate the presence or absence of the end-use or by the counts of the number of the units of the end-use in the facility. The UECs for the various end-uses are functions of appropriate exogenous variables, such as end-use features, dwelling characteristics, facility characteristics and facility income. The dependent variable in the model is daily energy consumption per facility in a given month, which is obtained from customer billing data by dividing total consumption by the number of days in the billing cycle. Using customers' actual consumption by month allows consumption to be modeled as a function of weather in that month, including the impact of heating degree-days (HDD) on main space heating and supplementary space heating load and the impact of cooling degree-days (CDD) on central air conditioning and portable/room air conditioners.

Finally, note that the unit energy consumption (UEC) is the average end use energy consumption for the segment for those sites where the end use is present, while the end use intensity (EUI) is the average end use consumption across all sites in the segment so that

$$EUI = Saturation\ UEC$$

Electric Space Heating

The electric space heating usage for customer h in month t is based on the equation:

$$UEC_{eheat,ht} = \frac{HEATLOSS_{ht}}{EFFH_h} = \frac{SURFLOSS_{ht} - SOLGAIN_{ht} - INTGAIN_{ht}}{EFFH_h}$$

where $HEATLOSS_{ht}$ is the net heat loss and $EFFH_h$ is the heating system efficiency. Since information on system efficiency was not collected in the customer survey, we assumed that $EFFH_h$ is constant across customers. $SURFLOSS_{ht}$ is the heat loss through envelope surfaces, $SOLGAIN_{ht}$ is the solar gain through all surfaces during heating periods, and $INTGAIN_{ht}$ is the internal gains during heating periods.

The heat loss through envelope surfaces is given by:

$$SURFLOSS_{ht} = \alpha_1 U_h AREA_h PERHEAT_h TDIFF_{ht}$$

where U_h is the overall conductivity of the shell, $AREA_h$ is the total surface area, $PERHEAT_h$ is the percentage of the enclosed floor area that is heated, and $TDIFF_{ht}$ is the differential between inside and outside temperature levels. We assumed that U_h is constant across customers. The surface area of the structure is modelled as a function of the total floor area:

$$AREA_h = \alpha_1 SQFT_h^{\beta}$$

where $SQFT_h$ is the square footage of the structure and β is the elasticity of surface area with respect to square footage. We assumed that β equals 0.5 (i.e. the square root) because the surface area of the building shell increases less than proportionately with floor area for standard shaped buildings.

The differential between inside and outside temperature levels is modelled as a function of heating degree days:

$$TDIFF_{ht} = \alpha_1 HDD_{ht}$$

where HDD_{ht} is heating degree days.

The solar gain through all surfaces during heating periods is modelled as a function of surface area and minutes of sunlight:

$$SOLGAIN_{ht} = \alpha_1 AREA_h MINSUN_{ht} WINTER_t$$

where $MINSUN_{ht}$ is minutes of sunlight and $WINTER_t$ equals one if t is a winter month.

The final model used in our analysis was based on a simplified version of the specification above. In particular, the variable involving minutes of sunlight was excluded because the necessary data were not available.

The internal gain during heating periods is modelled as a function of the surface area of the structure:

$$INTGAIN_{ht} = \alpha_1 AREA_h WINTER_t$$

Combining the preceding equations gives the overall model of primary electric space heating usage:

$$UEC_{eheat,ht} = \alpha_1 HDD_{ht} AREA_h PERCHEAT_h + \alpha_2 AREA_h WINTER_t$$

Electric Space Cooling

The electric space cooling usage is based on the equation:

$$UEC_{ecool} = \frac{HEATGAIN_{ht}}{EFFC_h} = \frac{SURFGAIN_{ht} - SOLGAINC_{ht} - INTGAINC_{ht}}{EFFC_h}$$

where $HEATGAIN_{ht}$ is the net heat gain and $EFFC_h$ is the efficiency of the cooling system. Given the limitations of the data, we assumed that $EFFC_h$ is constant across customers. $SURFGAIN_{ht}$ is the total convection heat gain through structural surfaces, $SOLGAINC_{ht}$ is the total solar radiant gain during cooling periods, and $INTGAINC_{ht}$ is the total internal gain during cooling periods.

The heat gain through the structure's envelope surfaces is given by:

$$SURFGAIN_{ht} = \alpha_1 U_h AREA_h PERCOOL_h TDIFFC_{ht}$$

where U_h is the overall conductivity of the shell, $AREA_h$ is the total surface area, $PERCOOL_h$ is the percentage of the enclosed floor area that is cooled, and $TDIFFC_{ht}$ is the differential between inside and outside temperature levels. We assumed that U_h is constant across customers.

The differential between inside and outside temperature levels is modelled simply as a function of cooling degree days:

$$TDIFFC_{ht} = \alpha_1 CDD_{ht}$$

where CDD_{ht} is cooling degree days.

The total solar radiant gain during cooling periods is assumed to depend on the total surface area of the structure and minutes of sunlight:

$$SOLGAIN_{ht} = \alpha_1 AREA_h MINSUN_{ht} SUMMER_t$$

where $MINSUN_{ht}$ is minutes of sunlight and $SUMMER_t$ equals one if month t is a summer month.

The final model used in our analysis was based on a simplified version of the specification above. In particular, the variable involving minutes of sunlight was excluded because the necessary data were not available.

The total internal gain during cooling periods is assumed to depend on total surface area:

$$INTGAIN_{ht} = \alpha_1 AREA_h SUMMER_t$$

Combining the preceding equations gives the overall model for electric space cooling:

$$UEC_{ecool,ht} = \alpha_1 CDD_{ht} AREA_h PERCOOL_h + \alpha_2 AREA_h SUMMER_t$$

Air Distribution

Energy usage of the air distribution system is modelled simply as a function of the square footage of the space:

$$UEC_{airdist,ht} = \alpha_1 SQFT_h$$

where $SQFT_h$ is the square footage of the structure.

Electric Water Heating

Electric water heating energy usage can be expressed as:

$$UEC_{ewheat,ht} = \frac{WHLOSS_{ht} + VUSE_{ht}}{EFFWH_h}$$

where $WHLOSS_{ht}$ is the heat losses associated with standby losses from the heating unit, $VUSE_{ht}$ is the heat losses tied to water usage, and $EFFWH_h$ is the efficiency of the unit. Since no information on system efficiency was collected in the customer survey, we assumed that $EFFWH_h$ is constant across customers.

Standby losses are assumed to depend on the number of employees and the temperature differential between the tank temperature and the inlet temperature:

$$WHLOSS_{ht} = \alpha_1 WHTDIFF_{ht} EMP_h$$

where $WHTDIFF_{ht}$ is the differential between the tank temperature and the inlet temperature and EMP_h is the number of employees.

The differential between tank temperature and inlet temperature is modelled simply as a function of heating degree days:

$$WHTDIFF_{ht} = \alpha_1 HDD_{ht}$$

The heat losses tied to water usage is also assumed to depend on the number of employees and the temperature differential between the tank temperature and the inlet temperature:

$$VUSE_{ht} = \alpha_1 WHTDIFF_{ht} EMP_h$$

Combining the preceding equations gives the overall model for electric water heating usage:

$$UEC_{ewheat,ht} = \alpha_1 HDD_{ht} EMP_h$$

Refrigerators

Energy consumption of refrigeration equipment is modelled as a function of the total number of units in use at the location:

$$UEC_{ref,ht} = \alpha_1 REF_h$$

where REF_h is the number of refrigeration units in use.

Freezers

Energy consumption of freezers is modelled as a function of the number of units in use at the location:

$$UEC_{fz,ht} = \alpha_1 FZ_h$$

where FZ_h is the number of freezer units in use.

Cooking Equipment

Energy consumption through the operation of cooking equipment is assumed to be constant:

$$UEC_{cook,ht} = \alpha_1$$

Miscellaneous (including Lighting)

A variety of other electric end-uses may be possessed by the customer. We assumed that energy consumption associated with these end-uses is constant across all customers:

$$UEC_{misc,ht} = \alpha_1$$

Various attempts were made to model lighting loads separately, but these were unsuccessful because of the low resolution of the self-reported lighting data. As an alternative, the lighting loads estimated through a recent whole building engineering simulation study were used for each type of business. This information used lamp, fixture and ballast counts from on–site audits and, therefore, provided the resolution needed to get good estimates. Attempts to model other secondary loads were not successful, so that the estimated end-use loads may over estimate actual loads.

Results

Statistical Model

The conditional demand model was estimated using ordinary least squares. Overall, the model performed well. Most regression coefficients had the correct sign and were significant at the five percent level or better. The value of the adjusted R-squared value was 0.76 and the F statistic was 3729.9. These statistics indicate that the final model fits the data very well.

Table 3: Regression Output

	Coefficient	Standard Error	t-value	P-value
Intercept	1723.9	534.7	3.22	0.0013
Prime space*SqM*PctHeat	0.0135	0.00175	7.68	<0.0001
Prime space*HDD*SqM*PctHeat	0.000047	0.000005	10.16	<0.0001
Prime space*SqM*PctHeat*BAS	-0.00624	0.00177	-3.51	0.0004
Prime space*HDD*Rest	12.03	7.546	1.59	0.1108
Prime space*HDD*Lodging	37.70	7.078	5.33	<0.0001
Sec space*HDD*SqM*PctHeat	0.00018	0.00002	7.35	<0.0001
Sec space*HDD*Public	-36.888	19.269	-1.91	0.0556
Sec space*SqM*PctHeat	-0.0748	0.00809	-9.25	<0.0001
Air distribution*Educ	-0.934	0.1979	-4.72	<0.0001
Air distribution*SqM*BAS	9.498	0.0817	116.20	<0.0001
Cool*CDD*SqM*PctCool*Optime	0.00050	0.00005	9.84	<0.0001
Cool*CDD*SqM*PctCool*Optime* Retail	0.00342	0.00012	29.18	<0.0001
Cool*CDD*SqM*PctCool*Optime* BAS	0.00034	0.00019	1.77	0.0774
Water heat*Employess*Optime	100.93	4.682	21.56	<0.0001
Refrigeration units	94.35	22.391	4.21	<0.0001
Cooking*Rest	205.18	2059.5	0.10	0.9206
Office*Computer*Employees	0.0168	0.00104	16.08	<0.0001
Adjusted R-squared	0.75			
F	3729.9			

The regression coefficients were used to calculate UEC values for major commercial end-uses. UECs were calculated for each customer possessing the end-use by substituting customer variables into the end-use equations. Normal heating degree days and cooling degree days were substituted to generate weather-normalized UECs for space heating/cooling and water heating. Weighted average UECs were then calculated across all customers possessing the end-use and across the various customer subgroups. Table 4 lists the average annual end-use consumption as well as the saturation rate.

Table 4: Average Total End Use Consumption and Saturation Rate

	End use consumption (kWh per year)	Saturation rate (%)
Lighting	220,621	1.00
Air distribution	227,795	0.43
Primary space heating	109,688	0.55
Secondary space heating	9,998	0.10
Space cooling	68,777	0.54
Water heating	38,185	0.39
Refrigeration	10,253	0.62
Cooking	2,460	0.08
Office equipment	17,884	0.89

Education

Table 5 shows the results for the education sector. Average annual total end use consumption levels were as follows: lighting 139,958 KWh; air distribution 254,429 kWh; primary electric space heating 138,659 kWh; secondary electric space heating 24,714 kWh; space cooling 16,644 kWh; water heating 62,668 kWh; refrigeration 7,250 kWh; cooking not modelled; and office equipment 17,884 kWh.

Table5: Education: Total and End Use Consumption

	End use consumption (kWh per year)	Unit energy consumption (kWh per m^2 per year)	Saturation	End use intensity (kWh per m^2 per year)
Lighting	139,958	38.3	1.00	38.3
Air distribution	254,429	69.6	0.69	47.8
Primary space heating	138,659	37.9	0.46	17.4
Secondary space heating	24,714	6.7	0.10	0.7
Space cooling	16,444	4.5	0.49	2.2
Water heating	62,668	17.1	0.34	5.8
Refrigeration	7,250	2.0	0.69	1.4
Cooking	-	-	0.01	-
Office equipment	18,492	5.1	0.96	5.1
Total				118.5

Health Care

Table 6 shows the results for the health care sector. Average annual total end use consumption levels were as follows: lighting 155,261 KWh; air distribution 174,835 kWh; primary electric space heating 61,147 kWh; secondary electric space heating 4,617 kWh; space cooling 10,589 kWh; water heating 15,011 kWh; refrigeration 8,960 kWh; cooking not modelled; and office equipment 17,884 kWh.

Table 6: Health Care: Total and End Use Consumption

	End use consumption (kWh per year)	Unit energy consumption (kWh per m^2 per year)	Saturation	End use intensity (kWh per m^2 per year)
Lighting	155,261	67.8	1.00	67.8
Air distribution	174,835	76.4	0.48	37.0
Primary space heating	61,147	26.7	0.59	15.9
Secondary space heating	4,617	2.0	0.16	0.3
Space cooling	10,589	4.6	0.63	2.9
Water heating	15,011	6.6	0.39	2.6
Refrigeration	8,960	3.9	0.78	3.1
Cooking	-	-	0.02	-
Office equipment	1,148	0.5	0.94	0.5
Total				183.3

Lodging

Table 7 shows the results for the lodging sector. Average annual total end use consumption levels were as follows: lighting 388,510 KWh; air distribution 191,277 kWh; primary electric space heating 264,572 kWh; secondary electric space heating 88,370 kWh; space cooling 18,345 kWh; water heating 11,983 kWh; refrigeration 76,587 kWh; cooking not modelled; and office equipment 606 kWh.

Table 7: Lodging: Total and End Use Consumption

	End use consumption (kWh per year)	Unit energy consumption (kWh per m^2 per year)	Saturation	End use intensity (kWh per m^2 per year)
Lighting	388,510	71.8	1.00	71.8
Air distribution	191,277	35.4	0.42	14.9
Primary space heating	264,572	48.9	0.74	36.1
Secondary space heating	88,370	16.3	0.03	0.4
Space cooling	18,345	3.4	0.42	1.4
Water heating	11,983	2.2	0.26	0.6
Refrigeration	76,587	14.2	0.66	9.3
Cooking	-	-	0.00	-
Office equipment	606	0.1	0.68	0.1
Total				134.7

Office

Table 8 shows the results for the office sector. Average annual total end use consumption levels were as follows: lighting 584,597 KWh; air distribution 573,797 kWh; primary electric space heating 161,881 kWh; secondary electric space heating 2,989 kWh; space cooling 28,403 kWh; water heating 68,456 kWh; refrigeration 8,417 kWh; cooking not modelled; and office equipment 64,639 kWh.

Table 8: Office: Total and End Use Consumption

	End use consumption (kWh per year)	Unit energy consumption (kWh per m^2 per year)	Saturation	End use intensity (kWh per m^2 per year)
Lighting	584,957	83.4	1.00	89.4
Air distribution	573,797	87.7	0.57	49.6
Primary space heating	161,881	24.7	0.59	14.5
Secondary space heating	2,989	0.5	0.09	0.1
Space cooling	28,403	4.3	0.74	3.2
Water heating	68,456	10.5	0.39	4.1
Refrigeration	8,417	1.3	0.61	0.8
Cooking	-	-	0.01	-
Office equipment	64,639	9.9	0.96	9.9
Total				171.5

Public Assembly

Table 9 shows the results for the public assembly sector. Average annual total end use consumption levels were as follows: lighting 82,977 KWh; air distribution 121,051 kWh; primary electric space heating 65,912 kWh; secondary electric space heating 8,853 kWh; space cooling 18,729 kWh; water heating 14,212 kWh; refrigeration 4,511 kWh ; cooking not modelled; and office equipment 1,366 kWh.

Table 9: Public Assembly: Total and End Use Consumption

	Unit energy consumption (kWh per m^2 per year)	Unit energy consumption (kWh per m^2 per year)	Saturation	End use intensity (kWh per m^2 per year)
Lighting	82,977	37.6	1.00	37.6
Air distribution	121,051	54.9	0.45	24.6
Primary space heating	65,912	29.9	0.54	16.3
Secondary space heating	8,853	4.0	0.07	0.3
Space cooling	18,729	8.5	0.46	3.9
Water heating	14,212	6.4	0.31	2.0
Refrigeration	4,511	2.0	0.78	1.6
Cooking	-	-	0.00	-
Office equipment	1,366	0.6	0.84	0.6
Total				86.8

Restaurant

Table 10 shows the results for the restaurant sector. Average annual total end use consumption levels were as follows: lighting 76,531 KWh; air distribution 61,127 kWh; primary electric space heating 57,464 kWh; secondary electric space heating 2,421 kWh; space cooling 6,277 kWh; water heating 39,543 kWh; refrigeration 8,544 kWh; cooking 2,462 kWh; and office equipment 142 kWh.

Table 10: Restaurant: Total and End Use Consumption

	End use consumption (kWh per year)	Unit energy consumption (kWh per m^2 per year)	Saturation	End use intensity (kWh per m^2 per year)
Lighting	76,531	72.2	1.00	72.2
Air distribution	61,127	57.7	0.42	24.5
Primary space heating	57,464	54.2	0.62	33.4
Secondary space heating	2,421	2.3	0.10	0.2
Space cooling	6,277	5.9	0.60	3.6
Water heating	39,543	37.3	0.30	11.2
Refrigeration	8,544	8.1	0.96	7.7
Cooking	2,462	2.3	1.00	2.3
Office equipment	142	0.1	0.84	0.1
Total				155.3

Retail

Table 11 shows the results for the retail sector. Average annual total end use consumption levels were as follows: lighting 146,293 KWh; air distribution 71,888 kWh; primary electric space heating 63,393 kWh; secondary electric space heating 1,461 kWh; space cooling 11,331 kWh; water heating 25,075 kWh; refrigeration 3,198 kWh; cooking not modelled; and office equipment 1,009 kWh.

Table 11: Retail: Total and End Use Consumption

	End use consumption kWh/year	Unit energy consumption kWh/m^2/year	Saturation	End use intensity kWh/m^2/year
Lighting	146,293	82.4	1.00	82.4
Air distribution	71,888	40.5	0.18	7.4
Primary space heating	63,933	36.0	0.53	19.0
Secondary space heating	1,461	0.8	0.08	0.1
Space cooling	11,331	6.4	0.47	3.0
Water heating	25,075	14.1	0.51	7.2
Refrigeration	3,198	1.8	0.44	0.8
Cooking	-	-	0.01	-
Office equipment	1,009	0.6	0.88	0.6
Total				120.4

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Conclusions

We noted above that electric utilities require accurate estimates of end-use energy consumption for power system planning, load forecasting, marketing and demand-side management. End-use consumption in the commercial sector refers to the consumption of space heating and cooling, air distribution, water heating, lighting and other specific uses. We distinguish between unit energy consumption (UEC) which is the average consumption for facilities in a building segment when that end use is present and the end use intensity (EUI) which is the average consumption across all facilities in a building segment whether or not that end use is present. In other words, we have the relationship

$$EUI = Saturation\ UEC.$$

Three main methods have been established for estimating end use electricity consumption: end use metering, calibrated engineering simulations, and conditional demand analysis (CDA). This report presents the methodology and results of a commercial end-use study for British Columbia, Canada. This study used CDA to estimate Unit Energy Consumption (UEC) values for the main commercial end-uses. The study generated UEC estimates for nine end-uses for seven building segments based on a sample of 1,126 commercial customers. Sixty-two months of billing data were used. UECs were calculated for each customer possessing the end-use by substituting customer variables into the end-use equations. Normal heating degree days and cooling degree days were substituted to generate weather-normalized UECs for space heating/cooling and water heating. The results were then weighted to the population of all commercial sector customers.

Weighted average total end use consumption levels were calculated across all customers possessing the end-use and across the various customer subgroups. Average total annual end use consumption levels were as follows: lighting 221,000 kWh; air distribution 228,000 kWh; primary electric space heating 110,000 kWh; secondary electric space heating 10,000 kWh; space cooling 69,000 kWh; and water heating 38,000 kWh. It was found that average total and end use electricity consumption per establishment varies considerably across building segments, with lighting or air handling typically the largest end use.

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Comparison of lighting simulation tools with focus on lighting quality

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Abstract

By the rise of concerns for global warming, reducing emissions via lowering energy consumption has become a necessity in every sector and the lighting sector is no exception. However, it should not come at the cost of lighting quality and user comfort which is a common practice in today's lighting design and energy reduction initiatives. The "energy reduction" view should change toward "value driven optimization" in which energy reduction is balanced against lighting quality and user comfort for optimization of the total value of the building. As the use of IT technology grows in lighting design, constant reviews of the software tools are necessary in order to evaluate their performance and ability to design value driven lighting.

The main objective of this paper is to compare different lighting simulation tools with respect to their ability to simulate lighting quality both artificial and daylight. The indicators for the comparison are defined based upon findings from another project "criteria for good lighting quality" that is currently being conducted at the same university. First, current numerical metrics for lighting quality are summarized. Then, different simulation tools are evaluated based on a literature study. The outcome of this research summarizes the strength and shortcomings of a number of simulation tools.

Key words: Lighting Quality, Energy Efficiency, lighting Simulation Tool, Day Lighting

Introduction

The building sector has a long history of focusing on cutting the initial (investment) costs. In recent years, cutting energy consumption gained extensive weight in these equations due to the rising concern of global warming and reducing emissions. Having these strong driving forces, it is a great risk that the focus in a building project will be too strong on initial cost and energy consumption rather than applying any comprehensive approaches for optimizing total facility life cycle values for the benefit of owners, users, environment and the society [1]. In the area of lighting design there is also a growing concern that the quality of the lit environment will decline in parallel to reduction of energy use as energy codes and standards come into effect [2].

The use of digital design tools is constantly increasing. This development provides great potential for earlier analyzes and simulations [3]. Not at least in the energy sector simulation tools have been developed and they are now standard tools in the planning process [4]. This is a positive development because it offers better control over the energy consumption of the building at the time of operation, however, it is accompanied by a great risk that it contributes to a sub-optimization of the building's value at the cost of other values e.g. user comfort and lighting quality. To avoid this risk it is crucial to strengthen simulation pertaining to the other types of values as well and to develop methods for a more value-driven building process that take in to account all facility life cycle values.

Lately there have been research efforts proposing multi-criteria frameworks where many different simulations are created. The results from these simulations are combined using a decision making framework, e.g. [5] [6]. This development creates possibilities to achieve a more value-driven building design process. However, for this to happen it is important that the simulations can simulate a wide range of values, e.g. lighting quality.

Lighting simulation is increasingly becoming substitute to traditional verification techniques as architectural and engineering students become familiar with computer modelling during their education [7][8]. Lighting simulation usage will also increase as a result of new and complex construction codes and certifications requiring sophisticated ways to demonstrate compliance [9]. But limitations of these simulations have been observed and developments are needed to better simulate lighting quality [10] [11].

This study is a part of a broader project that aims to position the design of the lighting system in a more value driven building process that enables an optimization of the total value of buildings for client, developer, tenants and users. The objective is to develop methods to employ lighting simulation softwares in the building process to ensure good lighting quality in a value driven building process. The main goal for this paper is to achieve a basic understanding of the metrics of lighting quality and to evaluate different simulation softwares.

To reach this goal the following questions will be addressed:

Q1: How can lighting quality be defined using lighting quality metrics?

Q2: Which characteristics of simulation software should be evaluated?

Q3: What are the available simulation software?

Q4: How can each of these lighting simulation softwares help to achieve better lighting quality?

The main method used to answer these questions was a literature studies.

(Q1): How can lighting quality be defined using lighting quality metrics?

To answer the first question (Q1) the literature were studied to find the metrics required to measure the lighting quality.

Lighting Quality

There is no universal definition of lighting quality. A number of different approaches have been suggested [12]. There is, however, broad agreement about the important dimensions of the luminous environment. These are illuminance, luminance, luminance distribution, uniformity, flicker rate, and spectral power distribution [2].

The IESNA Lighting Handbook Tenth Edition includes "visibility, task performance, mood and atmosphere, visual comfort, aesthetic judgment, health, safety and well-being, and social communication" as some of the psychophysiological dimensions of this complex topic. [13]

Based on Boyce's definition [12], in terms of human response, lighting can be divided into three classes.

> "Bad lighting is lighting that does not allow us to see what we need to see quickly and easily or causes visual discomfort. Indifferent lighting is lighting that does allow us to see what we need to see quickly and easily, without discomfort, but does not lift the spirit. Good lighting is lighting that allows us to see what we need to see quickly and easily, without discomfort, and which does lift the spirit."

The majority of the current codes and standards in the lighting sector can only eliminate bad lighting and at best leads to indifferent lighting. Developing more criteria, better utilization of daylight, broadening perspective on lighting design and increasing control of lighting at the individual level are means suggested by Boyce to achieve good lighting [12].

Perceptive Spatial Analysis of Color and Light (PERCIFAL) is a project defined within the Nordic research project SYN-TES (human color and light synthesis) that aims to develop criteria for good lighting. PERCIFAL encompasses eight defining visual concepts that are used to pinpoint the spatial color/light experience: light level, light distribution, shadows, light patches, specular reflections, glare, color of light, and surface color [14] [15].

Lighting quality metrics

In line with the above mentioned definitions of lighting quality, the most important indicators of lighting quality are identified. These indicators are defined below and their use in evaluation of lighting simulation tools are discussed.

Illuminance

Illuminance is the amount of light per unit area that is projected onto a given surface [16]. Standard unit for illuminance is Lux (lx) which is lumens per square meter (lm/m2). The most common measurement is horizontal illuminance that is defined as the amount of light incident on a real or imaginary work plane in an indoor environment. It has been estimated that this accounts for perhaps 90% of the day to-day use of lighting design softwares. Less common but still important is vertical illuminance, which determines, for instance, whether there is enough light to recognize faces on transit station platforms [17]. Other type of measurement include cylindrical, semi-cylindrical, and cubic illuminance, etc. Some of the metrics that are important include: illuminance, average illuminance and illuminance distribution uniformity. To be able to simulate lighting quality the design/simulation software should have the ability to report/present illuminance distribution at both task and room surface. (See Table 1)

Luminance

Luminance is the amount of visible light leaving a point on a surface in a given direction. This "surface" can be a physical surface or an imaginary plane, and the light leaving the surface can be due to reflection, transmission, and/or emission. The SI unit for luminance is candela per square meter (cd/m2) [18].

Some of the important metrics analyzed via software include: luminance, average luminance, luminance distribution uniformity. It is of special importance to have the ability to report/present luminance distributions, especially around windows and skylight to enable glare analysis. (See Table 1)

Daylighting aspects

Daylight has gained more attention over the recent years to the point that one of the top priorities of the IES (Illuminating Engineering Society) committee was to establish a useful description of “daylight sufficiency” as one dimension of the visual quality in daylit spaces.[19]

Daylight factor is the most commonly used metric in daylight analyses. It is defined as “the ratio of the internal illuminance at a point in a building to the unshaded external horizontal illuminance under a CIE overcast sky”. Daylight factor falls short in taking into account key parameters such as season, time of day, direct solar ingress, variable sky conditions, building orientation, or building location. Thus, daylight factor investigations cannot be effective when developing glare prevention strategies for different façade orientations [20].

A recently proposed development is the introduction of dynamic daylight performance measures to take into account quantity and character of daily and seasonal variations of daylight for a given building site [20].

Daylight Autonomy (DA) is defined as the fraction of the occupied times per year, when the required minimum illuminance level at the point can be maintained by daylight alone. In contrast to daylight factor, the daylight autonomy considers all sky conditions throughout the year. Required minimum illuminance levels for different space types can be directly taken from reference documents such as the IESNA Lighting Handbook [13].

Useful Daylight Illuminance (UDI) is another dynamic daylight performance measure. As its name suggests, it aims to determine when daylight levels are ‘useful’ for the occupant, that is, neither too dark (100 lx) nor too bright (2000 lx) [21, 22].

Continuous Daylight Autonomy (DAcon): In contrast to earlier definitions of daylight autonomy, partial credit is attributed to time steps when the daylight illuminance lies below the minimum [20]. (See Table 2)

Visual comfort

Visual comfort is one of the key elements of lighting quality, and the criteria changes depending on the application. Discomfort is most often caused by an excessive contrast in perceived brightness. It happens when our eyes try to adapt to two levels at once or when the contrast is sudden. Uniformity between visual task and background is a solution to prevent it.

Visual comfort calculations are inherently difficult to perform because they depend not only on the locations and brightness of light sources, but also on the apparent size (i.e. solid angle) of the light sources as seen from a particular viewpoint [23].

Glare

Glare is a subjective human sensation and occurs if the luminance is too high or luminance ratios are too high [13]. The latter can be divided into discomfort glare and disability glare and defined as the light within the field of vision that is brighter than the brightness to which the eyes are adapted [16]. Parameters that influence discomfort glare calculation are the directions, solid angles and average luminance of the light sources, and the background luminance for a particular viewpoint [24].

Glare Indexes

Visual Comfort Probability (VCP): VCP evaluates lighting systems in terms of the percentage of the observer population that will accept the lighting system and its environment as not being uncomfortable, using the perception of glare. VCP is mostly used in North America. The rest of the world uses different discomfort glare prediction systems [13].

Unified Glare Rating (UGR): the CIE produced a consensus system to predict discomfort glare. The VCP and UGR systems are based on and are applicable to electric lighting systems [13].

Daylight glare probability (DGP): is a recently proposed discomfort glare index that was derived by Wienold and Christoffersen from laboratory studies in daylit spaces (using 72 test subjects in Denmark and Germany). It is based on the vertical eye illuminance as well as on the glare source luminance, its solid angle and a position index. Compared to existing glare models, DGP shows a very strong correlation with the user’s response regarding glare perception [25].

Daylight Glare Index (DGI): DGI was developed by Hopkinson at Cornell in 1972. It was derived from human subject studies in daylit interiors for which the visible sky brightness and size was measured; however, it is not considered to be reliable when direct light or specular reflections are present in a field of view [26] [27].

CIE Glare Index (CGI): is the modified Einhorn equation given in [CIE83]. This formula is similar to the Guth DGR (Discomfort Glare ratio produced by Guth), but with a linear relationship to the source’s solid angle that results in better additivity (ie. breaking up light sources differently does not affect the results).[23]

Age Index is an index to address the vision issues of those with moderate vision loss caused by normal ageing and disease. These people may very well meet the visual requirements for driving license but can still experience great difficulty in daily life. For example, symptoms may arise in environments with low levels of contrast in combination with bright light sources. The ability to simulate this problem via lighting simulation tools help designers to prevent this kind of glare that is not possible to measure with ordinary eyesight.

There are also number of other indexes such as Predicted Glare Sensation Vote (PGSV), Osterhaus' Subjective Rating (SR) and etc. Some of these indexes have a correlation with each other. There are specific datasheets that provide the equivalent of an index in terms of another index. Each index has its advantages and limitations. For example some are developed only for artificially-lit environments (e.g. VCP, UGR) and some are designed to model glare from large sources (e.g. SR, PGSV); observer variability is taken into account in VCP and DGP; DGI can only be applied under conditions where direct sunlight will not enter; VCP cannot be applied to very small sources such as incandescent and high-intensity discharge luminaires but can be used for very large sources such as ceiling and indirect systems or to non-uniform sources such as parabolic reflectors and so on. One study [27] compares simulation results for five glare metrics (VCP,VGR,DGP,DGI,CGI) under 144 clear sky conditions in three different spaces in order to investigate the capacity of these metrics to predict the occurrence of discomfort glare and to hence support the design of comfortable spaces. It is found that Daylight Glare Probability gives the most plausible results. (See Table 3)

Color Aspects

Color is an essential property of light sources, objects, and light source/object interactions, and helps predict human perception under a wide and practical range of conditions. Psychophysical effects such as the relationship between the physical stimulus and human perceptual response should be consider as well. Color perception has three components: optical radiation, object and vision [13].

Correlated Color Temperature (CCT): The metric used to characterize the color appearance of the light emitted by a light source is the correlated color temperature [28]. Standard unit for color temperature is Kelvin (K). Light sources of the same color (metamers) can vary widely in the quality of light emitted. One may have a continuous spectrum, while the other just emits light in a few narrow bands of the spectrum. A useful way to determine the quality of a light source is its color rendering index.

Colour Rendering Index (CRI): The CIE color rendering index measures how well a given light source renders a set of standard test colors relative to their rendering under a reference light source of the same correlated color temperature as the light source of interest [28]. The general color rendering index Ra is a measure of the average appearance of eight standardized colors chosen to be of intermediate saturation and spread throughout the range of hues. If a color rendering index is not qualified as to the color samples used, Ra is assumed [18]. One of the most serious problems with the CRI is that the color rendering of saturated colors can be very poor even when the Ra value is good.A Color Quality Scale (CQS) is derived from modifications to the method used in the CRI [13_ENREF_29]. For the CQS, the eight samples used in the calculation of Ra have been replaced with 15 samples of high chromatic saturation spanning the entire hue circle [29].

Gamut Area Index (GAI): GAI represents the relative separation of object colors illuminated by a light source; the greater the GAI, the greater the apparent saturation or vividness of the object colors. As a result, light sources that balance both CRI and GAI are generally preferred to ones with only high CRI or only high GAI. Sources of illumination that have high values of CRI (CRI≥80) and high (but not too high) values of GAI (80≤GAI≤100) have been shown in several human factors experiments to be predictive of user acceptance. This area is defined as “Class A color” [30].

The human visual system has a limited range of capabilities. These limits, conventionally called thresholds, are mainly of interest for determining what will not be seen rather than how well something will be seen. The MacAdam ellipse are employed to set color tolerances for some light sources [13].

(Q2): Which characteristics of simulation software should be evaluated?

Simulations are software systems we construct, execute, and experiment with to understand the behavior of the real world or imaginary systems. This often includes a process of generating certain natural phenomena through computation [31].

Knowing the mechanism by which simulation tools work is essential in understanding their capabilities and constraints. The main characteristics of lighting simulation software fall into three main categories: rendering method, calculation algorithms and inputs and outputs. By understanding these methods and their application and depending on the project requirements and goals users can choose the right tool.

Photo-realistic versus physical-based

Lighting simulation software can be divided into two main classes depending on the rendering method used, even though they mutually benefit from the development of each method.

Photo-realistic rendering is mainly used for production of artistic images and places. It emphases on the appearance of its output rather than the techniques used to derive it. Anything goes, basically, as long as the final image looks nice. There is no attempt to use physically realistic values for the light sources or the surface reflectance [32].

Physically-based rendering (also known as predictive rendering), focuses on accurate representation and prediction of reality under given conditions and simulates the physical behavior of light as closely as possible in an effort to predict what the final appearance of a design will be. This is not an artist's conception anymore, it is a numerical simulation. The light sources in the calculation emit light with a specific distribution, and the simulation computes the reflections between surfaces until the solution converges [33]. This method will be the main focus in this paper.

Techniques

Radiosity (radiative flux transfer) is a global illumination algorithm used in 3D computer graphics rendering. In this technique the surfaces are divided into patches and these patches exchange light energy within a closed system. This method is usually limited to scenes with diffuse surfaces so that the solution matrix is manageable. It requires less computation power and therefore less time for simple geometries compared to other techniques. One of the advantages of this method is faster walkthrough view of the room because the simulation yields the total luminance distribution that is independent of the spectator's viewpoint [33] [31].

Ray tracing is a technique for generating an image by tracing the path of light through pixels in an image plane and simulating the effects of its encounters with virtual objects. The technique is capable of producing a very high degree of visual realism, usually higher than that of typical scan line rendering methods, but at a greater computational cost. Ray tracing is capable of simulating a wide variety of optical effects, such as reflection and refraction, scattering, and dispersion phenomena (such as chromatic aberration). Using Ray tracing new viewpoint requires a new ray tracing run which can be a problem in walk-through simulations. The technique is good for simulations where specular and partly specular materials are involved. It is the technique that gives the most physically correct results. Although There are still some phenomena that ray tracing cannot simulate accurately such as diffuse inter-reflections and caustics [31] [33].

Photon mapping is an extension of ray tracing. It is a versatile algorithm capable of simulating global illumination including caustics, diffuse inter-reflections and participating media in complex scenes. Extending ray tracing with photon maps yields a method capable of efficiently simulating all types of direct and indirect illumination. Furthermore, the photon map method can handle participating media and it is fairly simple to parallelize [34] (See Table 4).

Input

Input formats and methods play an important role in the model behavior and the accuracy of the simulation outputs [35]. As such they can be counted as a criterion in the comparison of different simulation programs. Accuracy of information provided by manufacturers of lighting products and optical properties of materials present in the indoor environment (walls, ceiling, furniture, etc.) as well as capability of the simulation programs in digesting such information are some of the topics that can be investigated. Major input factors are as follows:

- Creating scene geometry and surrounding landscape via graphical user interfaces (GUI) with or without their own CAD system, translators from computer aided design (CAD) programs, HDR rendering and imaging, text files, command prompt
- Optical properties of materials
- Objects and materials reflectance / ground reflectance
- Daylight analyzing factors (sky condition, weather data, location, date and time)

HDR

HDR High-dynamic-range rendering is the rendering of computer graphics scenes by using lighting calculations done in a larger dynamic range first introduced in Radiance lighting simulation software. This allows a preservation of details that otherwise may be lost due to limiting contrast ratios. Information stored in HDR images typically corresponds to the physical values of luminance or Radiance that can be observed in the real world which is essential for accuracy of lighting analysis and simulation. This is different from traditional digital images, which represent colors that should appear on a monitor or a paper print. There are other variants of HDR for imaging and photography as well. HDR file formats are used as inputs and outputs in a number of simulation tools. It has a great potential especially for glare analysis research [25, 36].

HDR images offer the advantage of encoding color gamut and luminance range information that is close to that of an original scene [37].

Output

Outputs of simulation programs can be numerical or visual. In many cases, numerical outputs are presented in spreadsheets for direct analysis by the user or they are fed to a 3rd party program for further manipulation. Visual outputs include images with data interpretation such as illuminance contours, photorealistic rendering, animation, and virtual reality. The most specialized form of output is an HDR rendering which could also be used as an input in the second cycle of simulation. Current tools offer a variety of output data, but considerable expertise is needed to interpret the results [34].

(Q3): What are the available simulation softwares?

There are several lighting simulation softwares in the market and their numbers are rapidly increasing. In this section, we reviewed a number of softwares that each specializes in different aspects of lighting quality. In addition to simulating quality aspects of lighting, usability, acceptability, availability and previous references in literature have been considered as the selection criteria.

Radiance: This software is one of the most influential physical-based simulation tools. It was among the first to employ integrative techniques. In addition, its core engine is used in a variety of other simulation tools.

DAYSIM which uses Radiance engine is specialized in daylight analysis.

The Evalglare software also uses the same engine and has the ability to detect a wide range of glare indexes. Radiance, DAYSIM and Evalglare becomes a powerful simulation tool as a package.

DIALux was chosen as it is one of the popular commercial and easy to use simulation tools. The tool employs a modified version of the radiosity technique and extended ray tracing for photo realistic visualization ability.

Velux Daylight Visualizer is a validated simulation and visualization tool for the analysis of daylight conditions in buildings. It has some special advantages like its multi-facet calculation method (Photon map, bidirectional ray tracing, irradiance caching) and user friendly interface.

VISSLA (VISualisation tool for Simulation of Light scattering and Aberrations) tries to simulate and predict how lighting is perceived by people with impaired vision.

(Q4): How can each of these lighting simulation softwares help to achieve better lighting quality?

To answer the fourth question (Q4), first evaluations of lighting simulations softwares found in the literature are described. After that different softwares are described with focus on the lighting quality metrics described above. This section ends with comparison tables of the different softwares.

CIE test cases for validating lighting computer programs

Commission Internationale de Eclairage (CIE) established an evaluation procedure of the output performance of lighting simulation packages [38]. The validation approach is based on testing different aspects of lighting simulation by individual test scenarios. The approach includes validation procedure for both artificial and daylighting (test case series 4, 5, 6) and based on theoretical principles where comparison is done with analytically calculated reference data to avoid uncertainties [39] [40].

Two types of reference data are used: data based on analytical calculation and data based on experimental measurements. The first is associated with theoretical scenarios that avoid uncertainties in the reference values. The second type is obtained through experimental measurements, where the scenario and the protocol are defined in a manner that minimizes the uncertainties associated with the measurements [38].

Comparisons in literature

Validation of Radiance against CIE171: 2006 showed good results for experimental test cases with point and square light sources (test cases 4.1 and 4.3); showed weak results in modeling circular light sources (test case 4.2); produced error in CIE references for test case 5.7; were capable of proper modeling of diffuse reflection (test cases 5.6, 5.7 and 5.8); had problems to simulate lambertian surfaces with reflectances > 80% (test case 5.8) [57].

Another study Shows Radiance has high accuracy, except in the indirect lighting test with reflectance values of 0.8 and above [58].

Pereira's study [43] concludes that Radiance is the best software for daylight analysis followed by Autodesk Ecotect Analysis and Design Builder at 2nd and 3rd places. However, the author observes a major problem in Radiances' lack of user friendly interface when used by architects, students and researchers not to mention, the problem of time consuming simulation runs.

A study by Labayrade et.al [44] assessed Velux. al [44] assessed Velux Daylight Visualizer 2's physical accuracy against CIE 171:2006 test cases. Although rendering quality and simulation time were dependent upon a global setting (RQ), overall they fell within reasonable ranges. The maximum and average error were 5.54% and 1.63% respectively. Thus it could be said that Velux Daylight Visualizer 2 could render and predict daylight levels of a space illuminated by daylight accurately for all configurations. (The detailed evaluation of Velux Daylight Visualizer 2 against test cases are presented here [59]. The results are well within the admissible tolerance ranges.)

Test results for DIALux evo (that is based on photon shooter calculation method) against CIE 171:2006 showed acceptable results for test cases 4.1, 4.3, 4.4, 4.5, 5.2, 5.3, 5.6. For the test case 4.2 only 58% of the values are within the measuring tolerance. The report does not exclude the possibility that in certain cases there may be deviations from reality [60].

Shikdar [42] compared DIALux 4.6, Ecotect 5.5 + Radiance, and Relux Professional 2007 by conducting two types of experiments based on CIE test case scenario, for point and area light sources without inter-reflections, to evaluate the accuracy of calculation outputs (illumination level and luminaire number). Simulated illuminance values were found to be identical to the analytically calculated values, which authenticates the acceptability of lighting calculation for similar scenarios. In all cases, scene modelling and luminaire definition ability were found to be good enough, with the exception of DIALux that lacked in building complex geometric descriptions in certain cases. Simulation accuracy were in acceptable ranges for simple geometric descriptions and direct lighting as well.

Lack of attention to lighting quality in most studies and in literature as well as overall lack of comparative materials, obliged us to use guides and datasheets of the software tools in some cases.

Radiance

Radiance is a physically-based Lighting simulation tool developed by Greg Ward at Lawrence Berkeley National Laboratory.

Radiance simulates light transport and reflection using Monte Carlo backward ray tracing [32]. Radiance uses ray tracing to follow light in the reverse direction and does not require the same discretization as radiosity techniques. This has significant advantages when the scene geometry is complex, and permits the modeling of some specular interactions between surfaces. In general, Radiance is faster than other simulation tools that use radiosity if the scene contains more than a few thousand surfaces or has significant specularity [33].

Dynamic simulation of Daylight Glare Probability (DGP) can be performed by Radiance and DAYSIM software using enhanced simplified DGP calculation[45].

Radiance is able to predict internal illuminance and luminance distributions in complex buildings under arbitrary sky conditions. Radiance uses ray tracing in a recursive evaluation of the luminance integral in a room [46].

Radiance continues to be the most influential simulation tool. It has received an extensive number of literature citations and was among the first to employ integrative techniques. As a general purpose tool, it solves a large number of lighting simulation problems. Radiance has been validated extensively [33].

The main drawback of Radiance is the lack of a user friendly interface. But it has the ability to import and export to other simulation software, e.g. the latest version of Design Builder exports Radiance files and since Autodesk Ecotect has some export functionality to EnergyPlus. This ability has also made it possible to incorporate Radiance into other software's, e.g. Evalglare and DAYSIM.

DAYSIM

DAYSIM is developed by the Lawrence Berkeley National Laboratory. Applications and features of DAYSIM include: expert daylighting, comparative analysis of the annual amount of daylight available in a building, lighting energy performance analysis, and analysis of using automated lighting controls (based on occupancy or light levels).

Inputs include: 3D model of the building, optical properties of material for all surfaces, climate data (amount of solar radiation at the building site over the course of the year denoted as TRY), and sensor file.

DAYSIM uses the Radiance simulation algorithms to efficiently calculate Illuminance distributions under all appearing sky conditions during a year and it can calculate annual illuminance or luminance profiles based on local climate data and a daylight coefficient approach [47]. The underlying sky model to calculate annual Illuminance profiles is the Perez all weather sky model.

DAYSIM is the only commercially available tool that can calculate both luminance and illuminance calculation in a single space. Thus it can predict available daylight at various locations in a single space as well as the brightness of the window in relation to those locations.

Various daylight metrics can be calculated and hourly/sub hourly reports can be produced. Daylight factor, DA, continues DA, UDI and the other metrics can be added if needed, by re-processing the raw output data [19].

In addition to DAYSIM, there are other software tools like ESP-r, Light switch Wizard#, SPOT (version> 4.0) that are based on Radiance engine which have the ability to simulate dynamic lighting [48].

Evalglare

Evalglare is a software that automatically detects glare sources. It is developed by the Fraunhofer Institute for solar energy system. Evalglare is based on Radiance and has the ability to export or import Radiance file formats (.pic or .hdr). Radiance images, produced in computer simulations, and HDR photos have the same file format and can be used interchangeably for glare analysis.

Evalglare determines and evaluates glare sources within a 180° fish-eye-image and provides much valuable data such as average luminance, background luminance, glare source luminance, and vertical illuminance values.

Evalglare can be utilized in a virtual model simulation and potential glare issues, in the final building, can be avoided in the design phase. Evalglare can evaluate glare issues caused by either natural or artificial light sources by using five different glare indexes: DGI, DGP, UGR, VCP, and CGI.

Additional software, such as DIVA-for-Rhino (Reinhart) and HDRscope (Inanici) utilize Evalglare to calculate the five glare indexes: DGI, DGP, UGR, VCP, and CGI [25] [49] [50].

DIALux 4.11.0.1 (Last Update: 2014.01.22)

DIALux is a light planning program for calculation and visualization. It can calculate daylight, interior and exterior lighting, road lighting and emergency lighting (according to EN1838). Its calculation methods is a modified version of radiosity and has photorealistic visualization with an integrated ray tracer. DIALux is one of the most used lighting calculation programs to date. It has 400,000 users in 180 countries.

For inputs, a room or an exterior scene can either be created in DIALux itself or it can be imported as a DWG or DXF file format. In addition, most of the major CAD applications can utilize DIALux STF data interface. Even a complete building model can be imported as a 3D object. Luminaires can be imported from electronic catalogues of more than 135 manufacturer or alternatively can be imported as photometric files like IES, EULUMDAT, CIBSE TM14, or LTLI.

On the output side, lighting design and calculation results can be saved as picture file formats (JPG, BMP), movies (AVI), electronic printouts (DXF, DWG, PDF), or they can simply be printed on paper. DIALux features photo realistic rendering via integrated ray tracing module, realistic rendering of textures and furniture, and interactive 3D visualization by providing walkthrough in virtual representation of the model. It is also possible to view the model in false colors which provides quantitative analyses in complex geometries at a glance.

DIALux calculations are based on international standards such as: EN12464 ISO 8995, EN1838, EN13201 and etc. The results are validated and tested against international standards (CIE 171:2006) and by the accredited lighting laboratory of DIAL [51, 52].

Velux

VELUX Daylight Visualizer 2 is a software tool dedicated to daylighting design and analysis. It simulates daylight transport in buildings to aid professionals by predicting and documenting daylight levels and appearance of a space prior to realization of the building design. The software permit generation of 3D models in which roof and façade windows are freely inserted. Other settings include the location and orientation of the models, the date and time of the simulation, as well as the sky type (from clear to overcast). In addition to photorealistic rendering, the simulation output includes luminance, illuminance and daylight factor maps [53].

VISSLA (Visualization and Simulation of Light scattering and Aberrations)

VISSLA is a computer software that visualizes how people with impaired vision, due to normal ageing, actually “see”. The aim of the program is to test if it is possible to visualize problematic lighting situations correctly. VISSLA simulates how an image is formed on the retina and visualizes what that retinal image will “look like” for someone. The simulation of the image formation on the retina takes both optical refraction errors (aberrations) and intraocular light scattering into account.

VISSLA simulates various visual degradations by filtering digital images from cameras or CAD models. It can transform high dynamic range images (HDRI) or CAD models of visual scenes into an “impression” as if they were seen through another person’s eye. VISSLA was developed as a tool to quickly perform a glare analysis of a scene. As of 2012, no such tool exists and light planners are referred to make cumbersome hand calculations using glare index equations [54].

Comparison Tables

Table 1 Comparison of simulation softwares in terms of luminance and illuminance calculations

Software/ Index	Illuminance	Luminance	Average Illuminance	Average Luminance	Background Luminance
DIALux	x	x			
Velux	x	x			
Radiance	x	x	x under arbitrary sky	x under arbitrary sky	
DAYSIM	x	x	x under all appearing sky	x under all appearing sky	
Evalglare	x	x		x	x

Table 2 Comparison of simulation softwares from daylight simulation point of view

Software/ Index	Direct sunlight	Daylight Factor(DF)	Useful Daylight Illuminance (UDI)	Daylight Autonomy (DA)	Continues Daylight Autonomy (cDA)	
DIALux	x	x				
Velux	x	x				
Radiance	x	x				
DAYSIM	x	x	x	x	x	

Table 3 Comparison of simulation softwares in terms of glare indexes

Software/ Index	DGP	DGI	UGR	VCP	CGI	AF	...
DIALux			x				
Velux							
Radiance	x			x	x		
DAYSIM	x						
Evalglare	x	x	x	x	x	x	x
VISSLA						x	

Table 4 Comparing simulation techniques used by simulation softwares (Based on [33], [55])

Tool	Algorithm	Dynamic Simulation Algorithm	Application
DIALux	-direct calculation -daylight calculation -Radiosity -POV ray tracer for images	-	
Velux Daylight Visualizer	Photon map -bidirectional ray tracing -irradiance caching		Conceptual stages in daylight application
Radiance	-backward ray tracing -scene radiance		
DAYSIM	modified version of the Radiance program “rtrace”	daylight coefficients &Perez	Expert daylighting analysis software
Evalglare	Radiance		Expert Glare analysis software

Discussion

This study shows that the most important indicators for light quality in existing softwares are: illumination, luminance, daylighting aspects, visual comfort, glare and colour rendering. The literature gives suggestions on definitions of quality of light that also include the emotional experience (E.g. Boyce "Good lighting is lighting that allows us to see what we need to see quickly and easily, without discomfort, and which does lift the spirit"). The analysis method PERCIFAL presents a number of visual concepts that facilitates in analyzing the character of the light in a space (SYN-TES / Anders Liljefors).

Types of visualization (photo-realistic vs. physically-based), rendering methods (radiosity, raytracing and photon mapping), and different types of input and output are identified as the important characteristics of existing simulation softwares.

In addition to lighting quality metrics, there are other factors that was considered in the evaluation of lighting simulation programs such as usability, acceptability, availability and previous references in literature. Considering these criteria, a number of software programs were identified and evaluated: Radiance, DAYSIM, Evalglare, DIALux, Velux and VISSLA.

The evaluation of softwares was done based on findings from literature, especially studies that were based on CIE171:2006 as well as the softwares' technical guide. Each lighting simulation tool has its own advantages (shown in tables 1, 2, 3, 4) and they should be used in the right application otherwise the results are not reliable. Import and export options in addition to the ability to integrate via plugins/platforms enable more comprehensive software solution packages.

It is important to note that each lighting simulation tool has its own advantages. The main objective of this comparison is not to find the absolute best software, but to identify the best software(s) for a specific application with respect to quality aspects of lighting. It is best to have a single solution that can cover all the aspects of lighting quality, however, that is not the case in reality.

An alternative solution is applying modularity in the design of simulation software that enables expansions via plugins or integration. There are a many softwares that have taken this approach most of which use Radiance as their core engine and integrate it with softwares such as Daysim and Evalglare. In order to have a value driven design approach, energy analysis should be conducted. OpenStudio tries to address this issue by integrating EnergyPlus, Radiance and SketchUp.

Parametric design approaches are gaining momentum in Architectural design over the recent years. Honeybee is a solution to integrate Radiance, DAYSIM, and Evalglare with EnergyPlus on top of Grasshopper parametric design platform. Diva for Rhino/Grasshopper is another solution in this regard [56] [26].

Validation of softwares is another factor that should be considered. A software's capabilities and accuracy cannot be judged merely based on the techniques used, rather it should be validated by academic references or the industry certification bodies. It is important to bear in mind that final results of a simulation run do not depend solely on the software itself; correct inputs are essential as well, not to mention how the outputs are interpreted [47].

Considering quality and user comfort, in the process of defining new standards for lighting, can change the views that are purely based on "energy saving" into "value-driven" perspectives which are inherently more sustainable.

This study can be followed up by doing more research via extending the number of indicators, studying and evaluating more softwares, and conducting more experimental studies. Evaluation processes need to be updated to stay relevant due to the fast changes in the softwares.

Conclusion

This study is a part of a broader project that aims to develop methods for using lighting simulation softwares in building design and construction to ensure good light quality in a value driven building process. The first step is to gain a basic understanding of lighting quality and to evaluate relevant simulation softwares. The outcome of this study is presented in this paper.

Most of the commercially successful lighting design and simulation softwares are easy to setup and use, but they do not cover many aspects of lighting quality. There are many simulation softwares that try to fill this gap based on the concept of modular design by specialization on one or a few aspects of lighting quality and energy saving. Combining different modules can build powerful simulation packages. However, they become complicated both in setup and usability to the point that they are mostly used by researchers. It is essential to simplify the setup process and GUI if they are to be adopted by a wider audience in the lighting and building industries.

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Inductively Coupled Power for More Efficient LED Lighting

Sam Woodward, Havells Sylvania Europe Ltd.

Abstract

Inductively Coupled Power for More Efficient LED Lighting

LED fixtures are helping to make building lighting more efficient. However the drivers traditionally used, which convert the 230V mains into low-voltage, constant-current to light the LED chips, present a weak point in the overall system: both in terms of efficiency (drivers are typically only 70% - 85% efficient and waste a lot of energy in the form of heat), they have a short lifetime due to heat-sensitive electrolytic capacitors, and subsequent present waste and recycling obligations, as well as multiple points-of-susceptibility to mains-borne transients and spikes and resulting short maintenance cycles.

Inductive coupling technology, for constant-current LED power offers a high-efficiency alternative (>90%), with long-lifetime and many other benefits.

Installation safety is ensured as 230V mains wiring is replaced by a low-voltage, high-frequency AC bus, and a robust central power converter. The inductive couplers clip onto the bus, without requiring an electrical connection, thereby reducing installation time (no cutting, stripping and connection of wires is needed!) and the flexibility to adjust an installation, such as the spacing between light fixtures, is introduced.

Whilst inductive technology itself is not new, its use for LED power is novel. The use for LED power represents the right problem for which this is the ideal solution, and with the rise in LED lighting it comes at the right time for those of us who are engaged in the efficient illumination of the built-environment. [2]

Background

The rise of the “LED era” has brought us many bright promises: long life, high-efficiency and low-maintenance. However, taking a system-wide view, the reality isn’t always matching the marketing message from the LED industry.

Traditionally, each LED luminaire has been powered and controlled by a dedicated driver (also known as electronic control gear), which is fed by a mains power supply (e.g. 230VAC). A group of fixtures would therefore have multiple connections to mains power.

Although not universally the case, such drivers have a relatively short life when compared to a properly-engineered LED light engine and/or LED chips, thus making them the weak-point in the system.

Likewise, typical driver efficiencies range from sub-70% to generally 85% for a good example. Of course, there are more efficient products that available on the market, but they tend to be the exception rather than the common case. This means that efficiency of the power-converter device has a significant effect on the overall efficiency of the system as a whole.

Inductive Coupling – An Alternative Method

In applications where there are multiple, relatively small, LED luminaires it can be advantageous to perform bulk power conversion from mains voltage to a *high frequency constant alternating current* which is then distributed the larger number of luminaires over a single twisted-pair cable.

Figure 1. AC/AC Converter – Mains 230V AC input, and HFAC output, 200W

The HFAC is then regulated and rectified to provide the constant-current DC supply which is required by the lumiaire's LED chips. This operation is performed close to each LED luminaire using a coupling device (see figure 2), which replaces the traditional LED driver.

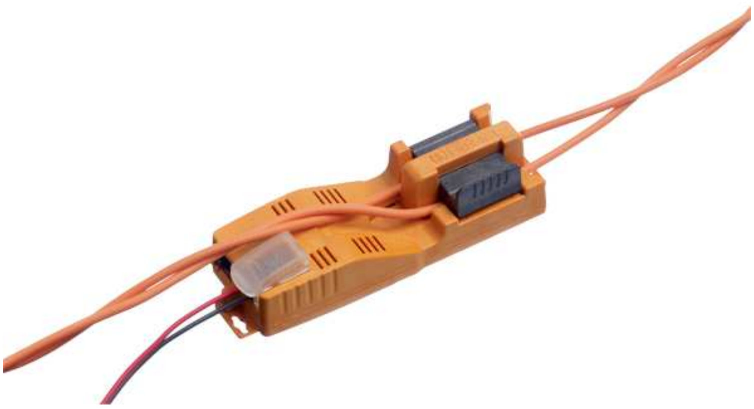

Figure 2. An Inductive Coupler – Replacing an LED Driver

Provided that the frequency of the AC current is high enough (e.g. 50kHz), highly-efficient inductive coupling can be used to connect a luminaire to the twisted pair cable without requiring any breach of the cable's insulation (i.e. no cutting, joining or break in the insulation).

System Performance

The efficiency of the AC/AC converter can be > 96% at full load and still > 93% at half load.

The AC/AC converter, connected to the mains, can have a power rating of several hundred Watts, enough to provide a supply to dozens of LED luminaires.

The efficiency of the inductive coupler should be > 95%.

Therefore the efficiency of the LED system, viewed as a whole, can be maximised, and is no longer limited by the efficiency of traditional electronic drivers.

Due to their high efficiency inductive couplers produce little heat, which extends their life. Furthermore the inductive couplers don't require electrolytic capacitors, normally the main ware-out mechanism of control gear.

Luminaire Dimming

LED luminaires can be individually controlled with a low-voltage control signal, connected to the inductive coupler, to change its output level.

The dimming range is from 100% to less than 1%, by controlling the DC output current. It can perform in a flicker-free manner, even at the lowest dimming level. The couplers' response to the input control signal of the inductive coupler can be configured to approximate to the exponential response of the human eye.

Installation Advantages

Example System Overview

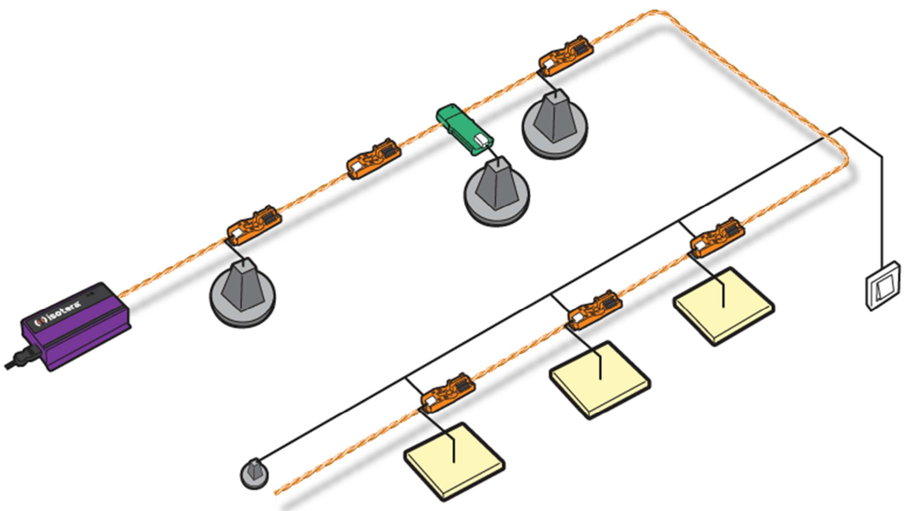

Figure 3. Example system showing power-hub (purple), inductive-couplers (orange), emergency-lighting module (green) and luminaires.

Speed

There are no screw terminals in the system and therefore installation is completely tool-free. The complete circuit consists of a single, uninterrupted twisted pair cable. Inductive couplers are clipped onto the twisted pair cable. This means that rather than taking several minutes per fixture (to cut and strip wires, to unscrew terminals and fix terminal covers), inductive coupler installation takes only a few seconds [1].

Flexibility

The contactless power transfer of the inductive couplers means that the insulation of the twisted pair cable is not punctured or breached. A useful side-effect of this is that couplers can be unclipped and moved to another location on the twisted pair cable without the need to repair or replace the cable.

Inductive couplers with different output characteristics (e.g. different drive currents, wattages) can be mixed on the same twisted pair cable, provided that the total load on the whole twisted-pair is within the capabilities of the main Power Supply.

Luminaires can be controlled individually or in groups, via a totally independent low-voltage control method. Luminaires controlled together in one group may receive power from multiple independent AC/AC converters.

System Safety [3]

Thanks to the use of inductive couplers which do not pierce the (double layers of) insulation on the cable used to distribute power to the LED luminaires, and additionally due to the 50kHz AC frequency used for transmission current, the system is inherently safe.

Open-circuit conditions on the main current loop lead to the immediate shutdown of the AC/AC converter and hence also inductive couplers.

The twisted pair cable is double-insulated to give it appropriate mechanical protection.

How AC affects the body depends largely on frequency. Low-frequency (50 - 60 Hz) AC is used in US (60 Hz) and European (50 Hz) households; it is more dangerous than high-frequency AC and is 3 to 5 times more dangerous than DC of the same voltage and amperage. Low-frequency AC produces extended muscle contraction (Tetany), which may freeze the hand to the current's source, prolonging exposure. DC is most likely to cause a single convulsive contraction, which often forces the victim away from the current's source.
The worst possible frequency for humans is 60 Hz, which is commonly used in utility power systems across the US, although 50 Hz as in UK frequency is also extremely dangerous. Humans are about five times more sensitive to 60-Hz alternating current than to direct current. At 60 Hz, humans are more than six times as sensitive to alternating current than at 5 kHz--and the sensitivity decreases still further as the frequency increases. Above 100-200 kHz, sensations change from tingling to

warmth, although serious burns can occur from higher radio-frequency energy. At much higher frequencies (e.g., above 1 MHz), the body again becomes sensitive to the effects of an alternating electric current, and contact with a conductor is no longer necessary as energy is transferred to the body by means of electromagnetic radiation.

"Neural and muscle cells are electrically excitable, i.e. they can be stimulated by electric current. In human patients such stimulation may cause acute pain, muscle spasms, and even cardiac arrest. ! Sensitivity of the nerve and muscle cells to an electric field is due to the voltage-gated ion channels present in their cell membranes. Stimulation threshold do not vary much at low frequencies (commonly referred to as Rheobase Constant Level).
However, the threshold starts increasing with decreasing duration of a pulse (or a cycle) when it drops below a characteristic minimum (so called Chronaxie). Typically, chronaxie of neural cells is in the range of 0.1–10 ms, so the sensitivity to electrical stimulation (inverse of the stimulation threshold) decreases with increasing frequency in the kHz range and above. It is important to note that the frequency of the alternating electric current is an inverse of the duration of a single cycle.
To minimize the effects of muscle and neural stimulation, electrosurgical equipment typically operates in the radio frequency (RF) range of 100 kHz to 5 MHz.
"In the mathematical description of the functioning of the nervous system, the chronaxie (or chronaxy) is the minimum time over which an electric current double the strength of the rheobase needs to be applied to stimulate a muscle fiber or nerve cell. The terms "chronaxie" and "rheobase" were coined in 1909 by the French physiologist Louis Lapicque.
With a 50 kHz AC current the maximum stimulation time in one direction is 10 microseconds, one-tenth of the shortest reported chronaxy as indicated by the purple dashed line in Fig 1. When applied to the hyperbolic curve of the neuron or muscle response we can see why the stimulus strength needs to be increased so dramatically to get any detection at all.

System Reliability

The reliability of the LED lighting system depends not only on the LEDs and control gear, but also on the integrity of electrical connections between parts of the system. As there are no wire terminations and connections when this inductive power system is deployed, the opportunities for connection faults are greatly reduced.

The twisted pair cable has no polarity.

In traditional systems, any voltage spikes in the mains will be delivered to every electronic driver that's connected to the mains power supply, with the risk of causing damage to multiple drivers in the building. With the inductive-coupled system the HFAC bus is separate from the mains supply and therefore such spikes/surges will not reach the couplers. Whilst this gives a bigger requirement for effective and robust filtering to be built into the AC/AC converter, it minimises maintenance at each fixture.

Summary

The use of inductively-coupled power for LED luminaires enables the vision of LED systems to become reality: long life, high efficiency, rapid installation and low maintenance. These benefits are combined with increased safety, to present a compelling reason to move away from traditional methods for this exciting light source.

References

[1] http://www.youtube.com/watch?v=gvee0HIfkMo

[2] Further information in Patent CA 2790890 A1

http://www.google.com/patents/CA2790890A1?cl=en&dq=inassignee:isotera+inassignee:limited&source=uds

[3] Source: Isotera Ltd system safety brochure.

Session

ESCO's

Title: "Business and technical concepts for deep retrofit of public buildings"

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Abstract

The IEA Annex 61" Business and Technical Concepts for Deep Retrofit of Public Buildings" aims to accelerate the building stock refurbishment rate significantly by providing research on high-performing Energy Conservation Measures (ECM) and adequate business tools overcoming at least two of the most important impediments for the implementation of energy efficiency in existing buildings: absence of both public funding sources and wide-spread knowledge on ECM bundling synergies. The revenue streams in the business models will refer to life-cycle-performance of the deep retrofit project. Performance-related business models like Energy Saving Performance Contracting (ESPC) are based on stipulations with strong incentives to meet life-cycle cost and investment budget targets and offer considerable virtues in comparison to the mostly practiced "owner-directed" business model. EPC already affords numerous best-practice records of building installations such as lighting systems, HVAC, CHP or Biomass heating. Annex 61 aims to integrate the thermal envelope and other deep retrofit measures in the EPC work scope.

The project is conducted by researchers and experts from Austria, Australia, Canada, France, Belgium, Denmark, Finland, Ireland, Sweden, Poland, USA and Germany. The work scope is related to corresponding national research projects.

The working phase of the Annex 61 has started in July 2013 and lasts about 3 years. The second biannual experts meeting will take place in Copenhagen, Denmark in March 17-19, 2014.

Annex 61 is divided in four consecutive Subtasks (ST):

ST A-*Bundles of Technologies*: Within the evaluation of deep energy retrofit case studies high-performing ECM bundles that will provide acceptable payback periods under existing national framework conditions will be identified.

ST B-*Business Models for Market Implementation*: In an interdisciplinary approach and based on the results of Subtask A business models for deep energy retrofit of buildings will be developed.

ST C-*Demonstrate Selected Deep Energy Retrofit Concepts*: Case studies will be prepared applying the business models and ECM bundles defined previously.

ST D-*Guideline:* Development of a decision making guideline for deep energy retrofit projects emphasizing low-risk approaches for early stages of design and decision making

This paper describes the approach of the research programme starting with the evaluation of accomplished deep retrofit and the lessons to be learned from that. It also describes how from the deep refurbishment project experience, bundles will be derived and how these bundles will be modeled and optimized with regard to the cost- benefit ratio. The paper provides information on which foundation the business models will be assessed, evaluated and analyzed. The research of business models will find a practical application in the setup of a pilot project, this paper describes the foreseen scope of work ending at least with an accomplished decision making process on a pilot case study. This paper also includes information on the dissemination strategy, which includes the design of guidelines for decision makers and stakeholders along the process of complex deep refurbishment projects.

1. Scope and Objectives of the Annex 61

1.1 Improve the use of high efficient business models

Many governments worldwide are setting more stringent targets for energy use reductions in government/public buildings. in Europe deep retrofit projects are mainly implemented by the "owner directed" business model. In this model the building owner engages external experts, mostly architects and civil-engineers for design, planning and preparation of the procurement process. The decision making criteria of the procurement process is usually the investment cost. The construction is executed by construction companies, supervized and finally approved by the architects and civil-engineers. The building owner is responsible for building-, facility- and energy management throughout the life-cycle of the building. The energy performance of these "owner-directed" retrofit projects hasn´t kept pace with the requirements to increase the number and rate of energy retrofits. Usually owner-directed business-models don´t succeed to improve the energy efficiency of existing buildings in an adequate level and mostly lack stimulation to meet efficiency targets and fixed investment expenses.
In recent years Energy Saving Performance Contracting (ESPC) has proven to be a very successful business-model bridging the weak points of the owner-directed models: ESPC business models are stimulating contract parties to achieve a high cost effectiveness (providing a better saving-investment ratio), better life-cycle cost effectiveness and a high degree of energy efficiency. With its life-cycle orientated cost structure the ESPC business models shape clear additional value in comparison to the owner-directed approach: ESPC business model structure typically sees the Energy Service Company (ESCo) providing the planning and implementation as well as the funding of the investment. The ESCo is responsible for achieving the guaranteed energy- and cost savings and has to take the financial risk if not. The average savings of ESPC projects are varying between 25 and 40% recapitalizing the investment and life-cycle cost of HVAC retrofits, CHP and biomass implementation within 5-15 years [1].

Nevertheless, in many countries the number of projects funded by ESPCs still do not form a significant part of the total investment budgeted by public institutions for energy retrofits. Annex 61 aims to increase the acceptance of ESPCs, and to broaden the implementation of deep energy use reduction through refurbishment of existing buildings using ESPCs and related or new business models [2].

1.2 Improve the Technical Scope of ESPC Business Models

Since retrofit projects, installed under such contracts, must pay for themselves from savings within a specified timeframe, deep energy reductions (>50%) have been difficult to achieve. Previous research conducted under Annex 46 identified and analyzed more than 400 energy efficiency measures that can be used when buildings are retrofitted. Measures include those related to the building envelope, mechanical and lighting systems, energy generation and distribution, internal processes, etc. Implementation of some individual measures (e.g. building envelope insulation and improved air-tightness, co-generation) result in significant reductions in building heating and cooling loads or minimization of energy waste, but require significant investments with long paybacks. This however sets up new challenges for the funding and the risk management of existing ESPC business models and also opens new opportunities: when different technologies are implemented together, or are "bundled," they can result in significant energy use reductions, require smaller investments, and consequently have shorter payback periods. An example of a measure bundle would be the improvement of the building envelope and simultanously the downsizing of the mechanical and energy generation system. Research under Annexes 49 and 51 showed that useful technology synergies result from consideration of energy use and waste — in buildings comprising communities or in building clusters where energy streams can be cascaded from one building to another and where energy waste streams can be used in low-exergy heating and cooling systems[3,4].

Bundles of energy-saving measures including the thermal building envelope are seldom applied when buildings and building clusters are retrofitted. Decision makers and ESCOs often lack knowledge about the synergy of different energy-saving measures available to them or about the efficiencies and return on investment that such bundles of measures can yield. To advance the scope of measures of ESPC and performance related business models from the technical perspective Annex 61 participants will develop applicable modeling structures that may help project partners and ESCOs to encompass a wider variety of retrofit measures and services in their project designs.

1.3 Improve the ESPC Business-Model

Analyses carried out in Annex 46 revealed differences among the participating countries in the way business models are used for implementing energy projects. In Annex 61 the Participants will seek to increase private-sector participation in the implementation of bundled energy projects. The innovative business strategies developed during the Annex 61 shall be applicable to the single country's business environment for leveraging private investment using limited public funding.

The conventional wisdom in ESPC is that, besides lacking modeling tools, deep retrofits are not practicable because of additional technical risks and the long paybacks challenging the known funding structures of ESPC. However, the development of new financing models offers the potential to significantly alter the equation. Which approaches could be considered? One aspect is to take additional life-cycle cost savings as added value into account of the funding which could be "avoided maintenance cost" of replaced installations and others. An other approach could be the combination of public and private financing, with private money sourced from bank loans, cooperative funds etc [5].

The development of new business models must be based on the understanding that the traditional method that separetely evaluates technically and economically individual energy conservation measures (ECM) will underperform compared to an integrated approach. The list of potential risks from ECM bundles has to be assessed sequentially for each stage of its life-cycle, starting with the design, calculation, procurement, construction and performance. From this point of view the de-risiking strategies could be derived from setting levels of performance and risk which are priced and blended accordingly. By addressing risk in this way, a common understanding on both sides is achievable and overall risk costs should be reduced. Moreover the number of firms, the breadth of the work and the variety of buildings should all play a part in the analysis — as coupling different buildings together should have the net effect of lowering risk and thus costs.

1.4 Application and Decision- Making- Guideline

Experiences from participating countries will be analyzed for applicability in other countries. The focus will be on technical and financial aspects of previous successful deep retrofit projects, on modeling of Energy Conservation Measure (ECM) bundles for buildings and building clusters and on the implementation of new pilot projects in each participating country. Resulting each participating country will develop specific business strategies to realize such projects. Within pilot-projects the developed modeling tools for ECM bundles and the new business models will be practically applied. With regard to the Annex 61 project duration of three years it will not be mandatory to present an accomplished pilot project. At least the feasibility study for one pilot project and the decision making process should be filed in interim and final reports.

The developed technical and business concepts and the experience gathered in the pilot project will be integrated into a decision-making guideline that will provide useful tools for governments to help meet their energy reduction targets using available funding. The Annex will also provide the private sector with greater opportunities to invest in the energy efficiency of public buildings by reducing risk and increasing potential project scope. The developed concepts will also be applicable to energy retrofit projects in private-sector buildings. The ultimate objective of this project is to increase the annual refurbishment rate of buildings and reduce energy consumption in retrofitted buildings in a cost-effective way by developing additional know-how and by using combined private-public funding.

1.5 Methodology

In recent years, numerous research efforts were undertaken in the EU member countries to advance energy efficiency in existing buildings. Still the implementation of this array of results is waiting to be accelerated in a significant way. One main impediment for this advancement is the lack of feasible implementation strategies which do not refer to public funding resources. With scarcity of public grants and supports most of the implementation strategies fail. Annex 61 offers both added values: it will not only contribute to R&D work on modeling tools but also research on business models as application tools for previous research results. The integration of private equity in the business models clears one of the crucial hurdles for the implementation strategies for energy efficiency in existing buildings.

Another important barrier of research work in the building sector is lacking market applicability and reproducibility. To assure that the Annex 61 results will be applicable under the national market conditions each of the Participants is required to set up and involve continuously a national steering committee. The working effort to be carried out in this Annex should be a mutual activity of stakeholders from public building owners, ESCOs, Public Private Partnership (PPP) Companies, project facilitators, funding industry, research labotaries, architects and engineers. The results of the Annex are collected into a decision making guideline to make sure that the decision making process is prepared and carried out transparently and repeatably.

The objectives of this Annex are to:

- provide a framework and selected tools and guidelines to significantly reduce energy use (by more than 50%) and to improve indoor environment quality in public buildings and building communities undergoing renovation
- gather and, in some cases research, develop, and demonstrate innovative and highly effective bundled packages of ECMs for selected building types and climatic conditions
- develop and demonstrate innovative, highly resource-efficient business models for retrofitting/refurbishing buildings and community systems using appropriate combinations of public and private funding such as ESPC and other concepts to be developed together with the building owners and other stakeholders
- support decision makers in evaluating the efficiency, risks, financial attractiveness, and contractual and tendering options conforming to existing national legal frameworks
- engage end users, mainly building owners and other market partners, in the proceedings and work of the Annex Subtasks.

The guidelines, best practices, and case studies will support different user groups and facilitate communication among them. The target audiences for the project outcomes include Participants in the decision-making process, specifically:

- executive decision makers and energy managers of public administrations
- ESCOs, PPP companies and general contractors
- financiers
- energy utility companies
- design, architectural and engineer firms
- manufacturers of ECM such as insulation, roofing materials, lighting, controls, appliances, as well as HVAC and energy generation equipment, including those using renewable sources.

1.6 Time Line and Management of Annex 61

The Annex was approved by IEA EBC Executive Committee, initiated in July 2013 and will continue for a period of three years. The Annex will be concluded by the end of December 2016. The following table represents the time schedule of each subtask process.

Tab. 1: Time Line Annex 61 in December 2013

Subtask Progress	Preparation Phase		Working Phase		
	2012	2013	2014	2015	2016

Subtask A	Case studies review
	Develop bundling options
	Technical and Economical Analysis
	Energy Efficiency Measure (EEM) bundles and Guidelines
Subtask B	Analysis of Business and Legal frameworks
	Develop Business Models of Deep Retrofit
	Support to case studies
Subtask C	Project feasibility studies
	Decision-Making Process
	Project implementation
Subtask D	Information collection
	IT-tool for decision makers and ESCOs
Report	
Annex meetings	
Annex workshops	

The Annex is operated by two co-Operating Agents; Subtasks A, B, C, and D are managed by Subtask Leaders/Co-Leaders. The co-Operating Agents for the Annex are Dr. Alexander Zhivov (USACE ERDC, USA) and Mr. Rüdiger Lohse (KEA, Germany). The Subtask co-leaders are:

Subtask A: Ove Moerk (Cenergia, Denmark) and Russell Taylor (UTRC, U.S.A)

Subtask B: John Shonder (ORNL, U.S.A.) and Marko Nokkala (VTT, Finland)

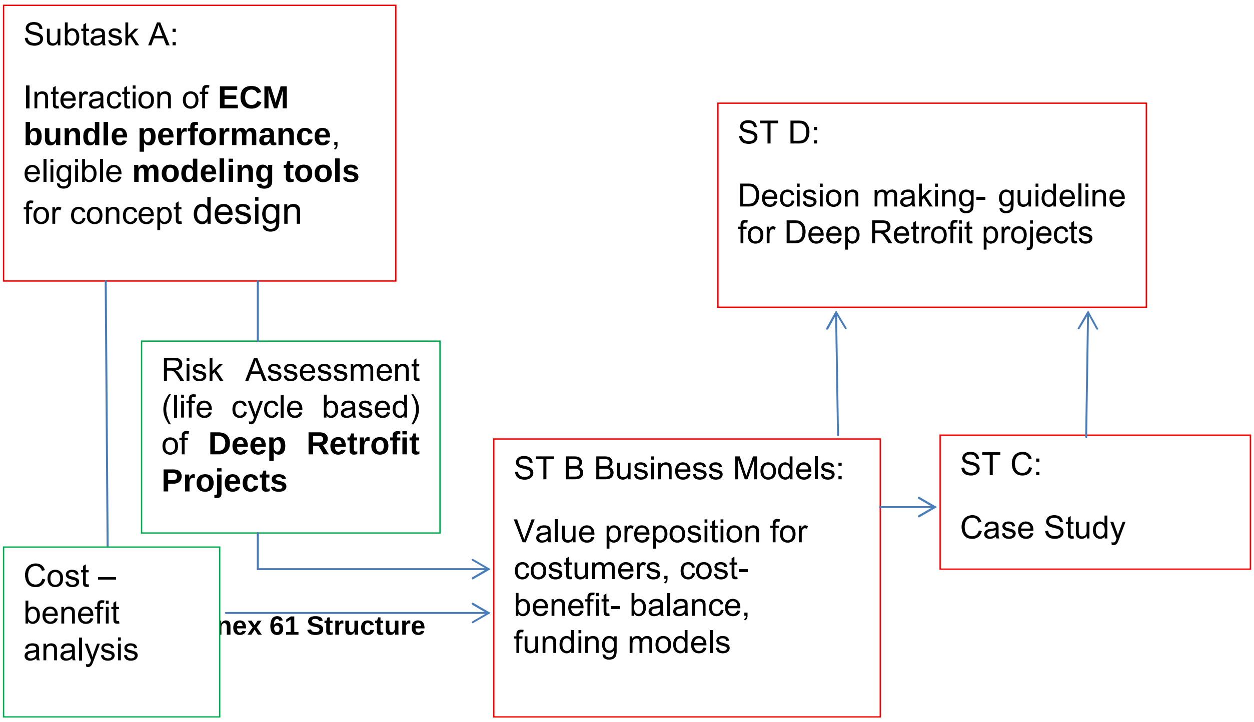
Subtask C: Cyrus Nasseri (DOE FEMP, U.S.A.), Tomás O'Leary (MosArt, Ireland)

Subtask D: Rüdiger Lohse (KEA, Germany), Heimo Staller (AEE, Austria)

The interim reports are presented to the Executive Committee of IEA ECB in biannual meetings in June and November. The coordination and determination of the working package contents of each Subtask is discussed in biannual working meetings in March and September. Subtask A and B have set up frequent telephone conferences. From February 2014 the Annex 61 Journal site will offer a platform dedicated for publications on deep retrofit projects. The Annex 61 homepage is www.iea-annex61.org.

2. Annex 61- Workplan

Annex 61 derives the new business models, the de-risking strategies and funding structures in Subtask B from the experience gathered with accomplished deep retrofit and existing business models in Subtask A. The decision making guidelines in Subtask D will refer to Subtask B results and the expierence made in the pilot project in Subtask C.



2.1 Subtask A: Prepare and Evaluate Case Studies on Existing Deep Energy Retrofit Concepts

Subtask A participants will leverage the currently isolated work of many entities across multiple countries to deliver a database containing case studies of completed deep energy retrofit projects within chosen building types. Lessons learned will contribute to Subtasks B and C which will be integrated into Subtask D. The result will determine bundles based on a blend of technologies and services working well under the existing national framework conditions. Based on the results from Annex 46 the main subjects will be:

- As a baseline to ensure usefulness and lasting value across countries, describe the national framework conditions; i.e. energy prices, legal requirements and standards for energy retrofits in existing buildings, climate data. Herefore a case-study template has been developed and distributed among national buildings owners, architects and others to provide the required data.
- Describe typical country specific building archetypes, mechanical and electrical systems, requirements to building environment and energy consumption of the selected building types in selected countries.
- Develop and use a common database checklist to harmonize the current isolated efforts (with the main focus on technical solutions, costs and cost drivers, and effected results).
- Review the projects in the database and identify how they might have been improved or gone deeper.
- The technological R&D issue will focus scenarios to blend different technologies and to determine packages of technologies and services (demand and supply side) that work under existing national framework conditions and acceptable payback periods.
- Develop, based on the above, an evaluation scheme useful for Subtask D in particular.

Subtask A effort will include the analysis of best practices for energy use reduction in future retrofit projects in different (selected) buildings, in particular office/administrative buildings, dormitories/barracks, and educational buildings. The team will develop basic climate-specific retrofit and service options for each participating country. These options will be modeled and shaped to achieve excellent energy and cost performance, most particularly by understanding the synergetic effects of different ECMs and services. The selected bundles of technologies and services will be further analyzed for constructability, life-cycle costs and outcome measures such as Greenhouse Gas (GHG) footprint. Then this prescriptive approach will be combined with a decision-making framework to help real-world decision makers evaluate their techno-economic applicability and value in particular situations.

Subtask A will result in a “decision-making guide for deep energy retrofit of buildings and building communities with energy-efficient and financially attractive bundles of technologies”; early results should help to choose the buildings for the pilot projects in Subtask D.

2.2 Subtask B: Business Models for Deep Retrofit of Buildings and Building Communities

Subtask B will partner with end users and other stakeholders to develop business models designed to ease the dissemination of, and to leverage the implementation of energy-efficient technologies and services in existing buildings. By combining technology bundles, funding sources, design and construction services, by assessing and overcoming the risks related to their performance, these business models will contribute added value to the marketplace, making deep energy retrofits more likely in public and governmental buildings.

Governments of some of the participating nations typically try to dedicate funding to sustainment, restoration, and modernization (SRM) of building stock. Although energy efficiency improvement is not the primary goal of these projects, many of the measures implemented using SRM funding are related to building energy use, e.g. replacing walls, windows, and roofs. Due to the associated long payback periods of these measures, ESPC projects have typically not included the building envelope or measures that do not have a strong impact on energy consumption. Combining SRM funds with third-party financing and reallocation of performance risk has the potential to significantly improve the economics of envelope measures. Reducing building heating and cooling loads reduces the required size of HVAC equipment and renewable energy sources, further improving project economics. However, combining SRM funding with third-party financing is perceived as a challenge under the current legal environment. Except for a few cases, uncertainties regarding contract structure, division of labor/responsibility among multiple contractors and the public building owner, and the distribution of savings have thus far prevented mixing of public and private funds.

In some of the participating European countries, administrators of municipal buildings do not have the opportunity to dedicate funding to SRM measures. In such cases, a cooperative venture between market partners and the public buildings owner must be developed. Market partners may provide the bundles of technologies and measures identified in Subtask A. For example, cooperative venture partners may consist of ESCOs that take over parts of (or complete) bundles. The proposed business models must take into consideration various market situations and situations where ESCOs do not manage the entire renovation contracts.

Subtask B will address such compelling key issues as the allocation of the risks for the performance of energy- and cost-saving measures. Early small-scale experience shows that ECM bundling is associated with longer payback periods and that there are additional risks for both sides. Long payback periods also add to the uncertainty of energy prices and of the cash flow from energy savings. ESPCs structures and the financing models typically in use do not yet accommodate these requirements.

Sustaining business models for deep retrofits that use ESPCs or that combine ESPCs and SRM measures must also consider the integration of operations, and user training to properly define the scope of the ESPC.

To ensure that results that may be viable under prevailing market conditions, the work in Subtask B should at least be aligned from the very early stages with the ESCOs and with the representatives of the end users such as the association of municipalities and governmental authorities.

Subtask B will focus on an understanding and analysis of individual national legal frameworks and their interpretations of different scopes of building and building community retrofits. Based on an analysis of different scenarios within these national legal frameworks, road maps for different project scopes will be developed. Subtask B will also develop recommendations for a contracting process that will accommodate the project scope and assure the quality of its execution. New adjusted to legal frameworks concepts for basic contract structures will be developed, along with the definition of different tasks, responsibilities, and risks of the various organizations that will participate in implementing cost-effective deep energy retrofit projects.

The goals of Annex 61 are to exploit opportunities by executing ESPC contracts in conjunction with routine SRM projects to achieve deeper energy efficiency. A key element of successfully combining private and public funds, as well as ESCOs and SRM contractors will be a construction project culture of collaboration and mutual trust. The Integrated Project Delivery (IPD) mechanism was developed for such objectives. Subtask B will develop specific strategies for implementing IPD in a practical way in this context and provide a contract framework for incorporating construction risk reduction and reward incentives, as well as strategies and know-how to manage the sequencing, execution, quality assessment and quality control.

The work in the Subtask B will be supported by a dialogue between the task team and external partners. Particular expertise in risk management and pooling is required to assess the private sector interest in co-financing the investments needed, when public funding is inadequate. Analogies for such Public Private Partnership (PPP) models can be found in, for example, road financing, where life-cycle models have been used in most countries for decades. These can speed up the investments and thus generate greater energy savings, also in financial terms. Models to engage private sector financiers and contractors in project design should be elaborated, as a response to the need to identify the benefits in a way that facilitates the involvement of contractors and financiers.

2.3 Subtask C: Demonstrate Deep Energy Retrofit Using Combined Government/Public and Private Funding or Only Private Funding, and Prepare Case Studies

Throughout the duration of the Annex, Subtask C will provide the Annex with critical information by implementing several national projects to demonstrate the feasibility of deep energy retrofits, to demonstrate the use of combined funding for such projects, and to generate "lessons learned." The main steps of Subtask C will be:

- *Feasibility Studies*. Participants will select one or more projects per participating country, and will collect whole-building and sub metered energy use data to establish the baseline, develop retrofit options, and of these, select the most energy- and cost-effective one. Life- cycle- cost based feasibility studies will also demonstrate the implementation of concepts using a combination of government/public and private-sector funding. The results of the study will have to be discussed with ESCos in an early stage to define the necessary preparative information to be provided by the costumer and the assisting facilitator for a successful tendering process.
- *Preparation of the Decision-Making Process*. The results of the feasibility studies will be discussed with the government/public building authorities with the aim of implementing one or more pilot projects.
- *Implementation. The experience g*ained during the planning and implementation phases of these pilot projects will be documented, and measured results (when available) will be compared with predictions. The r*esults of the national projects will be do*cumented in reports contributing to the Annex database and recommendations.

Subtask D: Develop an Overall Approach for Decision Makers and ESCOs That Emphasizes Low-risk Approaches for the Early Stages of Design and Decision Making

Subtasks A, B, and C will provide their results as input to this joint activity. Subtask D will be based on these results, and will develop a framework and clear decision models for government/public-sector decision makers and ESCOs, with a focus on the early stages of project identification and determination. The key criterion in the decision making process for the successful\ implementation of deep retrofits is the ability to help owners and ESCOs to rapidly agree on a valuable project scope and an appropriate business model. The guideline will include general information, but also allow the user to individualize a decision making process for deep retrofit projects based on lifecycle based cost-benefit analysis.

The data and schemes may be provided in an intuitive electronic interactive sourcebook that provides holistic guidelines for implementing deep energy retrofit of buildings and building communities using innovative business models. The sourcebook should allow decision makers to obtain extensive general information on the technical, business, legal, and financial aspects of building and building community renovation projects that achieve significant energy use reduction using a combination of public and private funds under their national frameworks. Currently the structure of the interactive guideline is to be prepared. At least two target groups will be adressed: decision maker level and the expert level. The decision maker level will receive a guideline which allows to understand the complex structure of deep energy refurbishments, describe the contents of each step and help with decision making criteria which could be eligible to reach specific targets. At least a basic understanding of the business- and the related funding models will be created by providing the basic structures and criteria to point out eligible business models. The expert level will adress the ESCos and the public building services and construction bureaus and will provide further information such as de- risking strategies along the decision making and planning process, a deeper insight description of the business model including an affiliation of tasks for the contract partners.

Users will be able to quickly increase their knowledge of the technical aspects of deep energy retrofits by assessing building type and climate-specific basic technology bundles, understand their synergistic effects and potential risks, and select appropriate business models based on the scope of work and the local financial and legal framework.

Based on this, the User will be able to access different retrofit design and framework scenarios, benchmark buildings, and use the pool of experience gained in the best practice examples to access information on energy-saving potentials and requirements for their individual building. The tool will allow building owners to define the scope of the deep retrofit project for their buildings based on the desired energy target for the building, available project funds, and a cost analysis of third-party funding.

The tool will use the Energy Concept Adviser (ECA) developed in Annexes 36, 46, and 51 to perform an analysis of the energy use of buildings and building communities, adjusted for results derived from subtasks A-C regarding the impact of building envelope, lighting, cooling, heating, and energy generation systems, as well as process requirements. The tool will also consider findings from several other Energy Conservation in Buildings and Community Systems (EBC) Annexes (e.g., Annex 37, “Low Exergy Systems for Heating and Cooling of Buildings”; Annex 49, “Low Exergy Systems for High Performance Buildings and Communities”; Annex 48, “Heat Pumping and Reversible Air Conditioning”; and Annex 45, “Energy-Efficient Future Electric Lighting for Buildings”). Among the major value-added features of the proposed Annex (compared with previous ones) are the database of basic (prescriptive, starting point) ECM bundles for deep building energy retrofits tailored to specific building types and climates as outlined above and a tool that allows selection of an appropriate business model for deep retrofit/refurbishment of buildings and building communities using combined government/public and private funding.

The dissemination is assured by the setup of national stakeholders committees which are closely aligned to the working process. All structures discussed and noteworthy will be discussed in the stakeholder committees to assure close- to- the market approach and bankable business and funding models. Furthermore, dissemination seminars are offered to the stakeholder groups as for the public building services, ESCos, facilitators among others.

Conclusion:

The project is targeting an important issue in the EBPD: how to increase pace and number of refurbishments of the building stock. The current situation of the public building sector can be described by increasing age, increasing refurbishment needs, ambitious policies, scarcity of appropriate funding and restrained access to loan programs. All these conditions are will lead that the scarcity of money will increase more and more. To not lose the ability of acting new developments and approaches or business models far beyond the existing and well- known practice have to be used. Under these circumstances the efficiency of money spent has to be increased dramatically. ESPC as a performance based revenue structure may currently be seen as one of the best performing business model in the HVAC refurbishment segment. Also, the ESPC revenue scheme opens the opportunity to make energy and other cost savings a constant in the funding structure of deep refurbishment projects. The project aims at advancing the basic structures of ESPC, which are the revenue streams, the performance guarantee on the deep refurbishment of the buildings. The collaboration of different EU countries and experts from the US, Canada and Australia is contributing global experience to the Annex work. The methodology is quite simple: learn from accomplished deep refurbishment projects, derive de- risking strategies, good practice examples, high- efficient ECM bundles. Currently the project is collecting verificated data from accomplished projects, including the planning phase predictions for energy consumption, investment costs and the technical description of the ECMs. As we learn in this process, these data are hardly available in most of European countries in an eligible quality. If available, the result show to some extent, that predictions and performance hardly meet in appropriate managed deep refurbishments. Still the research in that continues and it is to be expected, that the first results on high- efficient bundles and on the evaluation of deep-refurbishments will be accomplished end of 2014.

References

References (Use “normal” style or Arial 10 justified here)

Number references in the text in square bracket. Use “references” style here or Arial 10 justified single space. After each reference skip one line (inbuilt into style). See the examples below

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Latest Developments of the ESCO Markets in Europe

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Abstract

As of 2013, the ESCO market in Europe is still far from utilising its full potential. This paper presents a comprehensive overview of the European ESCO industry in 2013 based on the results from a large-scale survey carried out in 2012-2013 in 43 European countries. The observed market development between 2010 and 2013, trends in business practices, and factors influencing the ESCO industry evolution are described. Finally, the paper analyses the remaining barriers and the supporting factors as well as the successful experiences in Europe, and it recommends some additional measures that could further promote the ESCO markets.

Introduction

During the last decade the European Union and its Member States have dedicated large efforts to reduce energy wastage and improve energy efficiency on both the demand and supply sides. In parallel energy users have been increasingly interested in cutting their energy costs, applying sustainable construction methods, and searching for long term, trustful, financially viable solutions in energy use. Among many prerequisites, these aspirations need to be backed by financial solutions, technical and technological expertise, management creativity, market knowledge and communication abilities. Energy Service Companies (ESCOs) are able to offer many of these requirements and thus have become integral part of the European energy efficiency market.

The European Commission DG Joint Research Centre has regularly published information about the Energy Service Company markets since 2005 [1]–[3]. These ESCO market status reports are published every 2-3 years to provide a snapshot of the key developments of the national and the EU markets. The ESCO report series focus on collecting information about the market features and structures, barriers, policy background, financing opportunities and future expectations. The reports also summarize the findings at a European level, collect common barriers and success factors, and compare and contrast the national markets. While, the primary territorial scope of the reports is the European Union (EU-28), they also provide information about neighbouring countries. These reports have been useful for ESCO companies, interested potential ESCO clients, as well as policy makers at EU and national levels and energy efficiency experts. The current paper summarizes the findings of the 4th report in the series, depicts the status of the ESCO markets as of 2013 and the changes since 2010. The 4th report covers 43 European counties: the EU-28, Switzerland, Norway, the West Balkans, Turkey, Moldova, Belarus, Russia, Ukraine, Armenia and Georgia.

Recent European Policy Developments

In recent years the EU has increased the efforts to boost the European and national ESCO markets, in particular through Directives ESD (2006/32/EC) and EED (2012/27/EU), the EU EPC campaign, dedicated financing for energy efficiency such as the European Energy Efficiency Fund (EEE–F), IEE pand rojects, such as Eurocontract, EMEEES, ChangeBest, Permanent, Transparense, EESI, EESI2020, Combines, etc.

The Energy Efficiency Directive (2012/27/EU) is in the centre of this set of measures.

The most central element is Article 18. “Energy services”, which is a dedicated provision for the development of the ESCO solution. The articles requires Member States to

- ensure access to clear information about Energy Performance Contracting (EPC) contracts (in particular about guarantees and customers’ rights), financial instruments and opportunities for energy efficiency projects;
- encourage the development of quality labels;

- develop and ensure access to a list of certified and/or qualified service providers;
- support the public sector to use ESCO services ;
- identify and publicise points of contact, where final customers can receive help;
- remove regulatory and non-regulatory barriers;
- find a solution for proper handling of complaints by customers;
- enable independent market intermediaries; and furthermore
- ensure that energy distributors, distribution system operators and retail energy sales companies refrain from blocking the market of energy services and do not abuse their dominant position.

Furthermore, Article 7 mandates energy efficiency obligations for energy companies with energy saving targets equivalent to 1.5% of their final energy sales for final customers[1]. Another possible driver of the ESCO industry is Article 5, which requires the renovation of 3%/year of the total floor area of heated and/or cooled buildings owned and occupied by the central government. In addition, the leading role of the public sector is expected to disseminate successful renovation practices, including ESCO solutions, to other parts of the public sector and to private clients.

The recast of the Energy Performance of Buildings Directive 2010/31/EU (EPBD) is currently the main legislative instrument to reduce the energy consumption of buildings. Most of the requirements under this Directive are able to contribute to the increase of the ESCO market through promoting an energy efficient building stock and related public measures. Nevertheless the most relevant is Article 11 on Energy Performance Certificates, which has been found to be an important driver of ESCO contracts, by showing building owners a list of measures to be implemented to improve their buildings, thus increasing a demand for energy efficiency measures, while reducing transaction costs through mandating energy consumption information collection.

The European standard EN 15900:2010 defines energy efficiency services (EES) as an agreed task or tasks designed to lead to an energy efficiency improvement and other agreed performance criteria. According to EN 15900:2010 EES shall include an energy audit (identification and selection of actions) as well as the implementation of actions and the measurement and verification of energy savings.

The EU Energy Performance Contracting Campaign (EPCC) runs since 2012 as one of the key activities of DG Energy of the EU Commission. The aim of campaign is to enable country-specific discussion and capacity building of core stakeholders, and to strengthen the use of EPC, combining it with energy planning [4].

The Covenant of Mayors (CoM) is “the mainstream European movement involving local and regional authorities, voluntarily committing to increasing energy efficiency and the use of renewable energy sources on their territories”. When an authority signs for the CoM, they commit to reach (or exceed) the EU 20% CO_2 reduction target by 2020. The CoM signatories have to submit a Sustainable Energy Action Plan (SEAP) and report about its implementation. Promoting the ESCO market can be chosen as a key action to be able to reach these targets.

Methodology

The information in this paper is based on an online survey combined and complemented with personal and phone interviews. Information was also collected from national reports, scientific articles, legal documents, and grey literature. The principal methodology of the research was based on stakeholder information and large-scale surveying of ESCOs, international and national ESCO experts and experts in related fields, academia, and financial institutions. Using the snow-ball technique, interviewees were asked for further contacts who were then also contacted. After

[1] It is possible to introduce alternative policy measures.

analysing the survey results, drafts were sent out to the same and further experts and business representatives, who provided valuable comments.

The field research was carried out mainly between December 2012-June 2013 (online survey), and during November-December 2013 (interviews and comments). Around 300 informative answers were received,

The authors found that information was often hard to access, hidden, non-existent or available only on the local language; It has also been found that comparison of ESCO markets at a European level is limited by the fact that ESCO offers differ from country to country. ESCOs may be focused more on providing a full scale service from project preparation and auditing till monitoring or they may provide only part(s) of the value chain. They may be required to offer full guarantees or may be used as project managers. They are considered as financial alternatives (in Estonia, Hungary), or as organisers/managers (in Denmark), or establish strong long-term and often renewed partnerships (in France). In spite of the existing and well-received common definition offered by the EU legislation the notion of “Energy Service Company” may still mean a variety of similar businesses. All in all, the authors of this report experienced that the local definitions have converged much since the first report in 2005, and it is much easier to talk about the ESCO market and share experiences among countries.

It is particularly difficult to compare numerical features, such as number of companies, size and potential of markets because local studies, if existent, focused on local need for information in the locally most appropriate and/or traditional form (e.g. yearly vs. cumulated values, market size in terms of containing construction costs/preparation/transaction costs/considering energy saving values, being expressed in terms of monetary value, energy savings, etc.). Available values are thus not freely comparable.

Overall development of the ESCO markets during 2010-2013

Almost all of the EU markets have grown since 2010, and only few of them remained stable[2] (Austria, Estonia, Finland, Luxembourg), some remained embryonic (Malta, Cyprus, Lithuania, Latvia) or declined (Hungary. maybe Sweden and the Netherlands). Of the non-EU countries 5 have experienced a small growth and 8 have not changed. The growth has unfolded in size, referring to a larger number of companies/projects, as well as in strength reflected in market volume, more developed market structure, availability of institutions, or wider market coverage. The growth has been largely fuelled by the growth of demand, i.e. an expansion of interest from the side of potential clients (e.g. the public sectors in the Czech Republic, Denmark, the UK), who look forward to alternative financial and managerial solutions of energy renovations. In many countries dedicated European or national regulations have played important roles.

Types of ESCO firms

When markets have grown between 2010 and 2013, the new entrants have been mainly either small engineering/construction firms (e.g. in France, Ireland, Slovenia, the UK) and/or utilities opening up their businesses towards energy services. These energy companies are either lead by regulations on energy efficiency obligations or DSM (e.g. Denmark, Latvia and Slovenia, where obligations were introduced recently), or they offer energy services to attract new customers and increase loyalty of current ones (in Latvia, Austria, Denmark, Portugal). In Germany energy supply has been moving towards decentralised energy supply, and local and regional energy companies entered the energy services market in order to fulfil increasing interest from customers [5].

In the non-EU neighbouring countries, small local engineering companies, construction firms are most common ESCOs, and the involvement of agencies and international donor supported special vehicle bodies is typical. These latter ones provide general support for the market (financing, training, lobbying, etc.), while also implement (pilot) projects. They are the equivalents of public ESCOs in

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[2] There is disagreement amogst interviewed experts in the case of Austria, Sweden and the Netherlands, with some claiming a small growth, while others suggest that a decline has taken place.

European Member States. For example the Ukrainian and Moldovan markets were set up through these dedicated “ESCO agencies”.

The number of public ESCOs has also increased in Europe. New public ESCOs participate in the markets of Switzerland and Croatia. Hungary and France are in the process of introducing a public ESCO at the moment. In Russia, FESCO was established in July 2011 under the supervision of the Ministry of Energy. There are several public ESCOs in Ukraine, the first one, UkrESCO, was established already in 1998. The public ESCO model used by Fedesco, Infrax and Eandis in Belgium has been referred to as an “integrating” organisation. They contract public entities (clients) directly, and then subcontract the tasks to smaller, private suppliers on a competitive basis.

It is interesting that Energy Performance Contracting (EPC) is provided by different size of companies depending on the country. International large companies dominate the EPC market in Germany, Portugal, Belgium and mostly in Denmark and Sweden. However small companies can offer EPC in France, as opposed to the chauffage contracts generally carried out by large firms.

ESCO projects may even be carried out by a community of residents and the local businesses. The Meadows Ozone Energy Services Limited (MOZES) replaces the traditional energy suppliers in the region of Nottingham, UK. The MOZES ESCO is responsible for financing, installing, operating and maintaining PV systems that supply the residents – who own the company – with renewable electricity via energy supply contracts [6]. Similar idea has been advocated in Denmark by some municipalities [7], and the city of Gyor plans to transform their ESCO project (Raab-SOL) into a community lead district renovation, where the ESCO would be a facilitator rather than the implementer [8].

Facilitators and associations

The role of facilitators has not been duly acknowledged in the development of ESCO markets [9]. In a well-developed ESCO market, the buyers look for solutions to implement energy saving measures and/or property renovations and improvements. In this process they should consider the ESCO contract as an alternative to for example own implementation, leasing, outsourcing, etc. However, ESCO solutions are complex and are difficult to evaluate and compare – especially with alternatives. Most of the potential clients are not even aware of the existence of ESCOs. [9] collected a list of tasks that facilitators can and do perform: among them, overall information, amplification of the use of the ESCO concept, help interested customers prepare a tender or other announcement, select the winner, conclude a contract, monitor, verify savings, etc. From the clients perspective all of these and other steps in procuring or contracting an ESCO is – to say the least – challenging. It requires specialized knowledge in technology, financing, management, even communication.

There are a number of organisations that act as facilitators, for example national (or local) energy agencies (e.g. Motiva in Finland, SEAI in Ireland, the Graz Energy Agency in Austria, the Berlin Energy Agency in Germany, the Cyprus Energy Agency in Cyprus, etc.), (private) energy audit companies, some legal advisors and private facilitators (e.g. the Swiss market is expected to be launched with their help), or the EPC procurement advisors in the Czech Republic.

In a few countries the government can take up this task, for example the Ministry for Energy and Natural Resources in Turkey. In the non-EU/EEA countries, International Financial Institutions (IFIs) can typically act as facilitators, e.g. the World Bank/GEF in Armenia, EBRD in the West Balkans. IFIs are also present in some EU countries, e.g. EBRD in Romania and Bulgaria. In these countries, agencies are set up by the government or external donors to stimulate the energy services markets, e.g. the Energy Efficiency and Cleaner Production Center in Georgia or the Moldovan Energy Efficiency Agency.

There are 11 Member States, Switzerland and Ukraine that are aided by one or more associations, about one quarter of which were established since 2010. Furthermore, in Slovakia, Slovenia, Sweden, the Netherlands, and Switzerland the establishment of further associations is being discussed currently. There are several non-official organizations with similar functions, such as the ESCO Club in Poland, the Bulgarian WEC Committee, the ESCO network in Denmark, DEEM group in Hungary, the National ESCO Action Group in Ireland. Of the non-EU countries, Armenia has an ESCO association since 2006, Ukraine established an association in 1999, which stopped working after 5 years and was recreated in 2013, and there are plans in Turkey to establish one.

Contract types

The most commonly used contract type is still the chauffage contract. There are only a few countries, where EPC dominates, e.g. in Austria or the Czech Republic. Even in Germany, where EPC enjoys significant popularity as a result of the Berlin Energy Agency projects (Energy Saving Partnership model), only 8-10% of the market is covered by EPC.

During the 2010-2013 period clarity has increased in regards to contracts, either because of the creation or the dissemination of standardized contract models or guides or because of the introduction of definitions/standards (e.g. standardized contracts in the RE:FIT programme in the UK, the EPC standard in Norway, certification and standards in Austria, etc.), or on the contrary more flexibility was allowed in the contracts or in the contracting process than before (e.g. Denmark, UK), and a so called “negotiated procedure” is followed (Belgium).

In parallel to existing contract types, new contract types emerged during the period under observation:

- The traditional one-element contracts in France have been transforming to incorporate further elements, “small extras”, such as audits, financing, monitoring. As a result, contracts are better tailored for the needs of the client.
- Integrated Energy Contracting (IEC) is a newly applied model, whereby demand side and supply side measures are combined under an EPC project, with demand side measures enjoying a priority. IEC contracts are simpler than normal EPC, and therefore less expensive. IEC has been developed for the German and Austrian markets, and is used in Greece and the Netherlands, too [10]–[12].
- smartEPC was developed in Belgium, to integrate an innovative methodology of energy, maintenance, comfort and building value performance contracting.
- EPC+ is an ESCO contract model combined with state grants and forfeiting, in order to provide finance for large scale renovations of bloc-houses that are in particularly obsolete state [13].
- “Function agreements” or “comfort agreements” are common in Sweden. These are “chauffage” contracts, based on the provision of an agreed level of comfort or function, and the payment for energy is substituted with the payment of the level of service.

Target sectors

ESCO project are mostly implemented in the public sector (buildings and street lighting) and in industry, followed by commercial buildings. The preference depends on the national circumstances, the openness and willingness of the public administration, legal barriers, and on the industry side, factors such as size of the industrial sector and that of the individual installations, financial capacities, long-term thinking prevail.

It could be noted during the period 2010-2013 that sectors that were absolutely not attractive for ESCOs before, such as residential buildings and infrastructure (transport) were targeted by some projects. The problems related to these sectors include that they are decentralised and the projects tend to be small while experiencing higher transaction (information and face-to-face interaction) costs, the lack of trust from the potential clients is higher than in other sectors, potential clients have low liquidity and aversion to involve bank loans, and the split incentive problem is evident in most countries due to a high rate of renting, and the decision making process in multifamily buildings,etc.

The residential sector, public and private, has been given an increasing interest, in the form of pilots (e.g. the FRESH project in Italy, France and the UK, and the ESPARR project in Norway), but also in the form of ESCO-initiatives (e.g. in Denmark, Hungary, Estonia, France, Poland, Latvia, the Netherlands, Sweden, the UK, Germany and Switzerland). The Bulgarian government also expects energy savings through ESCOs in the residential sector according to their second NEEAP. These projects usually (but not always) combine some form of national or EU financial incentive with the ESCO technical project, therefore, a pure market based solution is not yet available. Nevertheless, the contracts are often guarantee based, i.e. the main role of the ESCO is to support the project with a guarantee.

Motivation of concluding ESCO projects

The primary driver of an ESCO project is the future financial gains from the investment. The client saves on energy costs, while the ESCO (and other contractors, financial players) raises profits. However, the focus of the ESCO contract shifts when it is concluded between a client and an energy service provider that is not doing the ESCO project for clear-cut profits. While we tend to consider ESCO projects as bankable on their own, it is increasingly common to engage in the field due to a mix of additional motivations, such as:

- improvement of image (since energy efficiency and climate change have a positive connotation);
- general renovation, which is then combined with the energy system revamping;
- improvement of comfort in the building or at the premises;
- triggering loyalty of customers and thus improving the position of core products;
- attracting more customers;
- complying with regulations.

If these motivations prevail, the ESCO-type investment can be cross-subsidised by the main product(s) of the contractor or from the client side, and can be added to the general renovation cost, for example.

Success factors during the period 2010-2013

There are a number of important drivers behind the above described market growth and transformation. The most important success factors are listed and explained below. In the period under observation, 2010-2013, it could be concluded clearly that a factor may be an important driver in the development of the ESCO market in one environment (e.g. the dedicated ESCO measures in Sweden), but may lead to only little change in others (e.g. in Spain the market is growing as a result of the supply side promotion rather than due to the mix of ESCO measures).

1. Legal and political drivers

1.1. **Long-term, manifested and credible commitment** by the government and/or the public administration to sustainable energy, energy efficiency and/or directly to the ESCO concept is amongst the key factors that can kick-start a market. For example in Denmark, a strong energy efficiency regulatory framework has been linked with a pronounced commitment to the ESCO solution by local administrations. A vehicle of this message could be the NEEAPs, the SEAPs, or other official energy plans, strategies that do not depend on, for example, election cycles. Such a commitment ensures a safe business environment, and therefore longer-term thinking by both ESCOs and clients, and provides for lower transaction costs.

1.2. **Supportive policy framework** is inevitable for the establishment and development of the ESCO market. When comparing the national markets, a general corroborative energy efficiency or sustainable energy regulatory background helps more than specific ESCO rules. For example, in the Netherlands ESCOs are not mentioned in legislation, nevertheless the general framework ensures that the energy services market can operate with a growing success. In Switzerland, stakeholders believe that the direct promotion of the market by policies is not needed (and does not exist at the moment), because by removing general legal hurdles the market can be expected to grow. On the other hand, there are markets where the market players do expect dedicated support or legal definitions, and where the generally energy efficiency friendly environment is/was not enough (e.g. Denmark, Norway, Latvia, Slovenia, etc.). Certification, transparency, information dissemination are amongst the functions stakeholders expect from dedicated legal acknowledgement or measures.

1.3. **Dedicated ESCO legislation and measures** have increased throughout Europe. While the ESCO Status Report 2010 concluded that the number of policies and actions set up with the objective of directly supporting the ESCO market were limited, the opposite can be seen between 2010 and 2013. Around one third of the EU/EEA countries enjoy dedicated ESCO rules. The level of success of these measures varies widely, though. Successful package was introduced in Greece (the 3855/2010 law describes the context and principles of an EPC, provides a model contract and prescribes the allocation of obligations and responsibilities between the ESCO and the client). In Italy Legislative Decree 115/2008 is the most relevant legislation for ESCOs, and it defines an ESCO, the energy service contract and energy service plus contracts. The Law on the Efficient Utilization of Energy in Final Consumption (adopted in 2008 and reviewed in 2012 OG 158/08 and OG 55/12) is the legal basis for energy services and ESCO operation in Croatia.

1.4. **Complementing measures** can also contribute to the success of ESCO markets. These are laws and regulations that are introduced for another reason, but have a positive impact on energy services as a co-benefit. The introduction of Energy efficiency obligation schemes (EEO) is mandatory in EU Member States via the Energy Efficiency Directive. The impact of EEOs on the ESCO market depends very much on its design. If energy companies (obligated parties) carry out energy services themselves, the system can be even competitive to market-based ESCO services. However, the system design may include the obligatory involvement of third parties, which will often be ESCOs. Similarly, the impact of White Certificates, especially if they are tradable it is more often seen as a driver, e.g. in Italy, Poland and sometimes in Flanders. Acquiring energy efficiency certificates through an ESCO implemented energy efficiency investment increases profits, thus increasing the demand for ESCO projects.

1.5. **Removal of regulatory barriers** was intentional in several ESCO markets. In Spain public procurement rules are adapted to long term (such as ESCO) contracts as a result of the procurement law (Law 30/2007, modified in Legislative Decree 3/2011). The contracting processes have been made dynamic and Article 11 of the Law defines the Public Private Collaboration Contract (PPCC) to suit best municipal conditions for ESCO projects. Energy-efficiency criteria were developed to be considered in the tendering process [14]. Similarly, the Swedish procurement act opens the way for EPC by accommodating it in public procurement practices.

Varied criteria in public tenders that involve requirements beyond initial costs, such as the consideration of life cycle costs, energy efficiency, social benefits, etc. have been introduces in many countries. These tender evaluations are particularly beneficial for ESCOs. For example in Croatia, Ordinance for Contracting and Implementation of Energy Services in the Public Sector (OG 69/12) created the legal conditions for energy service contracting in the public sector. The EBRD has a programme in Bulgaria and Romania to explore information about awareness raising, access to information about EPC, investigation of the legislative background, in particular procurement regulations and practices, as well as the general enabling framework and secondary legislation.

1.6. **ESCO and ESCO service standards** are able to improve the quality of the markets, on one hand because of the clear requirements towards the suppliers and because the clients can more easily selected trustful contractors. The European standard of energy services was introduced in 2010. There are a number of countries, which adopted their own official ESCO definition or a standard

2. Procedural factors, tools

2.1. **Tools, models and handbooks** have been produced that can be used at various stages of the project implementation. The EU has financed several projects addressing problems, such as project preparation, decision support, monitoring and verification, and even tools for the financing institutions interested in ESCO projects.

2. **Standard documents** have been advocated by a number of countries, where these have been prepared and used with more or less success. In 2011, after a few unsuccessful ESCO procurement projects, an ESCO procurement guide for the public sector was developed in 2012 in Finland [15], which is expected to improve trust. EU projects also developed several model contracts.

2.3. A notable development and important brick to a trustful ESCO-client partnership is when there is **flexibility in the content and the preparatory procedure** of a contract. This allows tailored services to the needs of the client. In Denmark municipalities that consider entering an ESCO contract, but have not done so, often perceive risks as too high because many ESCO suppliers are unknown companies. This problem is overcome with a larger flexibility in the contracts, and municipalities may opt out at any time during the project timeline.

2.4. Established **statistics system, data collection, the introduction of centralized data collection and management systems** have been found to decrease transaction costs, and therefore increase the accessible profits for ESCO projects. The Myenergy programme in Luxemburg is one key driver of the ESCO market. The building certificates introduced by the EPBD have been often referred to as core drivers, for example in Sweden, Portugal. The certificates can be used as baseline information. In Turkey, ESCOs are the primary suppliers of energy certificates of buildings, through which they can acquire larger projects.

3. Financing

3.1. A number of **EU and national level grants, financial incentives, preferential loans** have been identified that were used during the period 2010-2013. In the Czech Republic ESCO projects have been regularly combined with operational programmes [16], which has proven effective and has increased the achievable savings from 20-30% to 40-50%. The EPC+ contracts in Latvia combine the ESCO contract model with state grants and forfeiting, to finance large scale renovations of multi-apartment buildings that are in particularly obsolete state [13]. While these national and local financial (especially the non-refundable) grants may be destructive to the ESCO markets (because they compete with market based instruments, e.g. in Bulgaria, Hungary, etc.), credit lines from IFIs and national governments have been seen as a key success factor in kick-starting ESCO markets. Currently, they are very common in non-EU countries.

3.2. **Third Party Financing** (TPF) has increased, but it is still used only in one out of 10 projects. Since preferential loans are not available in Germany, financing is provided by banks, which are particularly active in this country. The openness of the financial sector has increased in the Czech Republic.

4. Information and awareness

The ESCO concept is increasingly recognised by authorities and considered as a valid alternative to own investment, leasing and other traditional practices by clients. The knowledge and understanding of the various ESCO models is also growing. As a result, in several countries, promotion efforts are not wasted on explaining the general benefits of the model, but rather new contract forms and flexible conditions can serve the needs of the individual clients better.

4.1. **Motivation** to refurbish sites, properties and buildings seems to increase. Energy efficiency investments are often driven by regular refurbishment. The experience of the municipalities that engage in an ESCO project in Denmark shows that the measures are done quicker and at a cheaper price. Some municipalities do not possess the appropriate capacities themselves. Environmental and climate awareness has increased at all levels. This has motivated policies on the governmental levels, and participation in projects at the client sides. In Scandinavia, one of the main drivers of ESCO (and other energy efficiency) projects is public image and environmental concerns.

4.2. **Awareness raising** activities have boomed – all of the countries in the current report indicated running awareness raising and information dissemination activities between 2010 and 2013. This activity was multiplied with the implementation of the EU EPC campaign, which visited almost all EU countries.

4.3. The **Covenant of Mayors** has served as a key driver, and as one of the main success factors in the Netherlands, Denmark, Cyprus, Croatia, but also in non-EU countries, eg. in Belarus, Ukraine, BiH, and Georgia.

5. Structural and market related changes

5.1. **Energy price** is one of the main factors influencing the demand of energy efficiency investments and therefore ESCO services. The steady rise in energy prices and energy taxes has improved the payback time of energy efficiency investments and increased the importance of energy efficiency in cost competition. The rise in energy prices has also increased the interest in energy conservation for non-energy intensive energy consumers. These can be combined with energy tax rebates (France and Italy) to further increase the profitability of ESCO projects. Similar measures are being considered in Moldova, Kosovo and Russia.

5.2. The **recovery of the construction industry** is currently a major driver and can be expected to contribute to an increase of ESCO projects both through the demand and the supply sides. In the Czech Republic less profitable types of measures (e.g. insulation) could be combined with profitable ESCO measures based on the increase of the construction activities and to reach deeper renovations. In the Netherlands, general renovations are extended to energy efficient refurbishment, too. In Denmark and Hungary, the decline of the construction sector has induced construction companies to search for new market niches, and thus enter the ESCO business.

5.2. The recent intensive proliferation of **ESCO associations** has meant a growing capacity to support the ESCO markets. In addition other types of **facilitators** also appeared and intensified their activities. About 40% of the EU ESCO markets enjoy the support of an association that is able to represent the companies.

5.3. In countries where projects and **project development processes** can be better tailored, and can be built up in a **step-by-step basis**, ESCOs have gained markets. Progressive projects are common in France, i.e. a client starts with a smaller project, and when trust has established, the client purchases the next service level or involves further buildings in the project. One successful project stimulates the contract for another. "Negotiated agreements" have been used in Belgium. After the tender is won by one company, projects are finalized through a "competitive dialogue".

2.7. Parallel **development of information and communication technology** was a driver in the Swedish ESCO market. The boom of **smart technology**, used in the energy management of buildings is predicted to pull several ESCO markets along.

Barriers during the period 2010-2013

The list of barriers has not changed significantly since 2010 throughout Europe, and all of the countries carry on to struggle with certain limiting factors. On the other hand, the observed growth and development is the result of successfully eliminating or decreasing one or more major barriers. The most important and common barriers are discussed below.

1. Legal and political barriers

1.1. **Unstable legislation** can block ESCO markets. In an economy where laws change rapidly, without (proper) public and expert consultations and not allowing enough time for the business sector to prepare, long-term contracts, such as ESCO contracts are not viable, because of the high risks. Such unstable legislation has hindered the markets of Hungary, Slovenia, Italy, and Spain.

1.2. The **lack of official and/or generally accepted and known ESCO definition and/or certification scheme and/or standards** hinders the ESCO market. While there is an EU-wide definition for ESCOs, in many countries, it is the company that decides whether to refer to itself as ESCO or not. This has caused significant confusion in the Netherlands Croatia and other West Balkan countries, where the notion of ESCO is popular, even if the company does not actually deal with energy services. On the other hand, in France, the number of ESCOs is underestimated because more general contracts often involve elements of ESCO services, however the whole contract is not an ESCO contract.

1.3. There are a number of examples of **contradicting interpretation of legislation** regarding the ESCO businesses. For example in Sweden, there is no common agreement whether a municipality-owned energy company is allowed to offer energy services outside their municipality of origin or not. Today, practice varies, and therefore some municipalities allow their companies to operate throughout the territory of Sweden while others restrict their activities to one municipality [17]. Public institutions in the Czech Republic are often afraid of using EPC because of the unclear rules (e.g. about project registration, approval and accounting). The lack of acceptance of the ESCO concept by the public financier is a crucial issue. In the Czech Republic, the so called "organisational units of the state" (OUS) are not able to apply EPC because they are legally bound not to receive or provide grants based on the Act no. 218/2000, Section 49. The Ministry of Finance, which administers these OUSs, even considered EPC as an act for "cheating". The Heat Supply Act does not allow selling services, i.e. comfort as a commodity in Slovakia.

1.4. **Procurement** related barriers used to be the central hurdles for ESCO projects. As of 2013, many of the national legislations have resolved the tendering and the public management of EPC projects. Nevertheless, problems do remain. There are still a lot of countries where the savings in energy costs cannot be transferred into another budget line, such as operation or human resources. There is a legal problem with the possibility to participate in tenders by all ESCOs. In several countries (e.g. Italy, Hungary, Sweden), a company that has carried out a feasibility study cannot participate in the competition for the renovation project. This is overcome only by “grey” solutions, e.g. the establishment of an extra company only for the preparation phase, etc. in Belgium, a solution has been found through the use of negotiated agreements (see at the drivers section). Procurement laws and practices are deemed as too complex in Cyprus, completely blocking the initiation of ESCO projects. But this problem is also evident in Croatia and Finland, even though procurement practices are also considered as drivers there.

2. Institutionalization and project tools

2.1. The **lack of facilitators** is considered as a market gap, i.e. without facilitators some ESCO markets cannot be started. For example, in Cyprus and Malta, neither the supply, nor the demand side has been able to push the market through its tipping point.

2.2. The **lack of proper measurement and verification practices** is a problem. Without a credible method to prove energy savings, projects can be debated by the participants. This has lead even to court cases (Latvia), or failed projects (Sweden). Measurement of projects where the public budget is also involved, because of a grant, is imperative. For example in the Czech Republic, the Kozloduy Fund does not use reliable measurement and verification system and therefore the appropriation of the financial grant can be debated. Similar situation has been in Hungary with the Panel Programmes and other building renovation programmes that required a certain level of energy performance improvement, but which was not checked or certified.

3. Financial barriers

Finding financing and finding appropriate financing solutions both remain to be a common barrier. Although TPF is used more often than before, according to [18] only 1 out of 10 ESCO projects incorporates external financing. In the other cases, either the ESCO or the client will provide the budget for the project.

2.1. The most regularly referred problem relates to the **accounting of EPC projects as loans** by public authorities. This has two consequences. On one hand, municipalities and other authorities are not allowed by their government to participate in ESCO projects, because these are considered to fall under the **EUROSTAT methodology ESA 95** (European System of Integrated Economic Accounts), and therefore are added to the value of the government debts, which are on the other hand limited by the EU legislation (Directive 2011/85/EU on requirements for budgetary frameworks of the Member States and related regulations). At the moment there is no satisfactory solution for this, although some countries (e.g. Denmark) does not consider municipal ESCO projects as loans. But almost all other countries either clearly interpret the EUROSTAT methodology as a barrier to ESCO projects (e.g. Slovakia, Czech Republic, Poland), or does not clearly take a stand (Spain). The other problem is that **liquidity** and **creditability** of the public administrations are limited, especially after the financial crisis. Therefore they are reluctant to take “loans”, and/or banks are reluctant to offer loans to them.

2.2. The classic problems with **banks** remain, i.e. **low awareness and motivation**. Nevertheless, there are a number of ESCO financial products, which are seriously underutilized. In Hungary, about 3-4 banks have ESCO-related products, which are not utilized because the application process has several requirements which are either not possible to comply with (deadlines, list of administrative documents, etc.), or the costs and/or effort would be too high compared to the benefits of winning the loan.

2.3. There is a strong **aversion to loans** by potential ESCO clients, especially by the public administration, the private residential and the private tertiary sectors. During the financial crisis, accessing loans was reduced and companies were afraid to get engaged with loans. They fear that the financial crisis situation can repeat, and loan repayment seems to them too risky. At the same time, banks are also much more careful in selecting the safer partners, and from their point of view an ESCO project is too risky, and thus unsafe.

2.4. **High transaction costs** remain to block the start-up of ESCO markets. ESCOs still prefer large projects, that have a better cost/benefit ratio. At the same time, pooling (or bundling) has gained more and more popularity, and is done in Austria, Germany, Luxembourg etc. In Denmark, an average of 60 buildings can be found in a pool. On the other hand, smaller ESCOs struggle to find the way in-between. In Sweden, clients prefer tenders for projects with a value of less than €56 million, in order to avoid the complicated EU level procurement.

2.5. If national financial grants are commonly used for energy efficiency renovations and the announcement of the grants and the volume of their budget is rhapsodic, clients will put their bankable projects on hold to wait to see if at least parts of the investments could be covered from the appearing grants. This is the case in Hungary and Latvia, where the risky legal environment and the incalculable financial support have had a major role in the decline of the ESCO market.

3. Market and partnership problems

3.1. There is still some **lack of trust by the clients** in the markets, although a lot has been done to overcome this barrier (see “drivers” above). Lack of trust usually originates from inhomogeneous ESCO offers in the market, lack of competition, lack of experience of clients, ESCOs and financial institutions, absence of credible and visible reference cases with a clear client focus, unclear definitions and failed contracts, and unstandardized measurements and verifications. Lack of trust is among the key barriers in the non-EU countries, and this problem is highly euphemized in the West Balkans and post-soviet countries, because of fear for corruption.

3.2. **Lack of well-established partnerships** between ESCOs and sub-contractors was also identified, as well as mistrust from the side of contractors towards clients, due to an increased risk of unstable and insolvent customers. Furthermore, partnerships between the ESCOs and subcontractors were marred as a result of financial difficulties of the construction sector in general, whereas many previously reliable companies went bankrupt or had change business.

3.3. **Failed projects** have been seen to affect the markets very deeply. Even one critical project may undermine the successes in a short time. For examples in Sweden the ESCO market has decreased radically in 2009 due to an EPC procurement in Stockholm, where disagreement between the parties could not be resolved. The effects of this dispute were negative on other companies, too and created mistrust in the EPC business model, market recovery is slow since then. In Finland public procurement rules were not always followed properly, and the projects had to be stopped for investigation or be cancelled. In Latvia, a project was taken to court due to the disagreement about the results of the project. The same happened in Hungary and has contributed to a bad reputation for other companies, too, which have to restart market information campaigns and building up trust.

Conclusions

The key conclusions of the previous JRC ESCO status reports were that the ESCO markets of the European countries vary widely in terms of development and size, as well as in features and frameworks. While this statement is still accurate on the whole in 2013, the markets have more in common than before.

First of all, almost all of the European markets have grown since 2010, and only few of them remained stable or declined. The growth has unfolded in size, referring to a larger number of companies/projects, as well as in strength reflected in market volume, more developed market structure, availability of institutions, or wider market coverage. The growth has been largely fuelled by the growth of demand, i.e. an expansion of interest from the side of potential clients (e.g. the public sectors in the Czech Republic, Denmark, the UK), who look forward to alternative financial and managerial solutions of energy renovations. Nevertheless, there are countries where crucial regulatory drivers, information dissemination, financial solutions were introduced during the observed period (see section on drivers above). Interestingly, growth could be realizised even in countries where the regulatory framework poses a problem for ESCOs (e.g. in Italy, Greece, the industrial segment of Slovakia, etc.).

The European ESCO markets are clearly developing both in terms of volume and in complexity. The following is a list of features, (one or more of) which are characteristic of the more mature markets

- the ESCO concept is **known and understood**. Clients may need additional information about the specific offer and contract types offered by suppliers, but a decision between own investment, ESCO project, outsourcing, etc. is done internally by the client;
- the market is **demand driven**, meaning that (potential) ESCO clients actively search for suppliers, and define their needs and requirements for an energy services project or package, announcing them and waiting for alternative solutions, which can be compared to each other;
- there are **alternative contract forms**, several of them available in a standard format or supported with guidebook that were prepared by independent organisations but with the involvement of market stakeholders.
- there are **alternative financial solutions**, including client-financing, bank involvement.
- **transaction costs are low**;
- there are **facilitators**, who can help clients decide about the available offers, while they can help the supplier side, too, by lobbying, general promotion, training, certification, etc.
- the **policy framework does not hinder** the ESCO projects, nevertheless there is no need for dedicated “ESCO laws”;
- **grants or preferential loans** – if available – **do not favour, nor disqualify ESCOs**. They should be **gradual** and provide non-refundable subsidies only for measures that have a very long payback time, but are socially beneficial, and that are combined with more attractive measures in order to achieve e.g. deep retrofit or complex project or favour special social groups, etc.

The above criteria are not universal by any means. A certain market may need to fulfil only part of the points and/or may have one or more key features. It is also not an aim or a politically arguable aim to strive for a “theoretically” developed ESCO market actively – a lot of times, markets will decide for themselves and/or the frameworks will distort the value of the ESCO business.

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Selection criteria for energy performance improvement measures in traditionally constructed non-domestic buildings

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Abstract

In the context of the energy-led refurbishment of traditionally-constructed non-domestic buildings, a two-stage Delphi exercise has been carried out in order to identify the criteria that professionals consider to be important in the selection of energy performance improvement measures, and to establish their relative importance. Based on the opinions of a panel of experts, 22 assessment criteria were identified, covering short-term outcomes, long-term issues, end of life issues, and whole life impacts. A paired comparison survey enabled the weightings of relative importance for the criteria to be determined. Measures fell into one of three broad groups, expressed on a scale of 0-100, such that the sum of the weights of all 22 measures was 100. Measures of relatively high importance (8±1%) included capital cost, potential energy and carbon savings, financial payback and impact on the building's vapour permeability. Measures of medium importance (4.5±1%) were impact in internal air movement, loss of significant original building fabric, impact on internal layout, appearance and occupant comfort, environmental impact and availability of grants or subsidies. Eight further measures were ranked of low importance (2-3%).

Introduction

In the UK, about 40% of energy use and CO2 emissions is associated with existing buildings, so significant reductions can only be achieved by refurbishment. This paper deals with traditionally-constructed non-domestic buildings which are common in the building portfolio of service sector and public sector organizations, providing them with a presence in many major city centres. The professionals responsible for making decisions on the measures to be adopted in order to improve their operational performance are faced with a plethora of technical and other information, which must be weighed carefully against the needs and aspirations of their corporate employers. Following a review of the literature on the decision support tools available for such professionals, Strachan and Banfill [1] developed a seven-step generic decision support tool for energy led refurbishment of non-domestic buildings, which could be used by property managers who are responsible for a non-domestic building or a building portfolio. The seven steps are:

1. Building assessment to gain a holistic view of performance and record it in a database.

2. Identification and selection of energy demand interventions, such as change in occupancy culture and behaviour, changes in lighting and appliances, and changes to building fabric, services equipment and controls.

3. Simulation of building energy performance after application of energy performance improvement measures (EPIMs) to reduce energy demand.

4. Identification and selection of energy supply interventions, through adoption of low carbon / renewable energy sources.

5. Simulation of building energy performance after application of both demand and supply interventions.

6. Energy management action plan to advise the user on how to manage their improved building.

7. Continuous improvement through periodical review of performance.

The objective of the work described in this paper is to develop step 2 into a practical tool for the property professional responsible for an existing office building of traditional construction, defined as pre-1919, mass masonry construction, originally single glazed, originally without insulation materials built into the fabric, and likely to have high air infiltration levels. These professionals are faced with a range of EPIM alternatives in a complex decision making process that can be classed as Multiple Attribute Decision Making (MADM). MADM is characterised by alternatives, numerous attributes, attribute weights and numerical values in inconsistent units that are difficult to compare [2]. In this study the alternatives are the EPIMs, which have multiple attributes that can be assessed both qualitatively and quantitatively. From this mixture, MADM involves the evaluation of information and prioritisation of solutions, which in turn requires some form of weighting of the various attributes. Since individual decision makers are likely to have different opinions on the relative importance of each criterion, it is important to develop a consensus. This was done using a two-stage Delphi process which, first, established an agreed set of assessment criteria and, second, developed weightings for each criterion.

The Delphi technique

Delphi is a method that supports comprehensive decision making, planning and problem solving, and has been used in a wide range of sectors – construction, education, healthcare, information technology, marketing and transport [3-8]. The core of the method is the obtaining of statistically valid consensus between a group of experts in a specific field, based on their knowledge and experience, implemented through a series of iterative questionnaires, combined with controlled, anonymous feedback [9]. The strength of Delphi is that it creates an environment where each expert can think independently, without the pressure of a group scenario, where forceful personalities can unduly influence the thinking of the group [10] and even cause direct confrontation [11]. An appropriate Delphi expert is one that is a highly skilled specialist in the subject [12] but is also open to revision of their views when presented with new information [13]. Between ten and fifty experts are considered suitable for Delphi [14], so recruitment of experts can be challenging, but a greater challenge can be the time taken within and between each survey round to allow the experts to consider the content of each round of questions and between each survey round for the researcher / facilitator to analyse and draw up feedback of the expert views [11].

Weighting multiple assessment criteria

Establishing the relative importance of a set of assessment criteria that have been drawn up in a Delphi process is complex because of the conflicting nature of the criteria. Among available methods Bartlett [15] reviewed fixed point scoring, rating, ordinal ranking, graphical weighting and paired comparisons. Since methods requiring participants to distribute points over several items at once are too demanding [16] the paired comparison method has the advantage of asking for only two criteria to be considered at once: participants compare their relative importance in a systematic questionnaire. The comparison is facilitated by a numerical scale but the questionnaire can be lengthy because every criterion must be assessed against every other one in the set and the comparisons must be carefully organized to minimize respondent fatigue.

Methods

A panel of 13 experts was recruited to take part in a two-stage Delphi process, each with specialist experience within one or more of five relevant sectors:

(i) Client. Experts who work within an organisation with a significant building portfolio, who are involved in the management and works to that portfolio.

(ii) Guidance. Experts who work within an organisation who set standards or guidelines for construction standards or experts who are involved in and promote research into energy in buildings.

(iii) Heritage. Experts working within an organisation who work to safeguard the historic built environment.

(iv) Industry. Experts who work within the construction industry.

(v) Non-heritage. Experts who have a technical background with an understanding of the historic built environment but are involved in a broader range of building types.

Delphi stage 1

In stage 1, the experts developed an agreed set of criteria for the use of built environment professionals in assessing the suitability of an EPIM for an existing building. This involved three rounds of online questionnaires, administered by Surveymonkey®. In round one, each participant received a questionnaire consisting of an initial list of 15 criteria, with seven questions, some in yes/no format and some requiring a comment (table 1). Their replies, elicited over two further rounds, led to an agreed list of 22 criteria, which were then used in stage 2. Experts were given two weeks to reply to each round of questionnaires, in line with recommended practice [11].

Table 1 Delphi survey questions

Number	Question	Response format
1	In your opinion, does the list contain sufficient criteria to assess the suitability of an Energy Performance Improvement Measure?	Yes/No
2	Are there any criteria that should be added to the above list?	Yes/No
3	If yes, then please describe what additional criteria should be added.	Comment box
4	If yes, then please explain why these additional criteria should be added.	Comment box
5	Are there any assessment criteria that should be omitted from the above list?	Yes/No
6	If yes, then please describe what criteria should be omitted.	Comment box
7	If yes, then please explain why these criteria should be omitted.	Comment box

Delphi stage 2

In stage 2, the agreed assessment criteria were weighted in terms of their relative importance in the decision-making process, using a paired comparison questionnaire. In order to compare every criterion against every other criterion, the number of paired comparisons N is given by the formula:

$$N = m (m-1) / 2$$

where m is the number of criteria. The 22 assessment criteria therefore generated 231 pairs of comparisons, which were presented to each respondent as a nine-point Likert scale (table 2).

Table 2 Paired comparison questionnaire (respondents tick the chosen box) and scores assigned

		Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
	Criterion A	☐	☐	☐	☐	☐	☐	☐	☐	☐	Criterion B
Bipolar scoring		+4	+3	+2	+1	0	-1	-2	-3	-4	
Unipolar scoring		9	8	7	6	5	4	3	2	1	

Experts were asked to compare criteria A and B and tick the appropriate box. The comparisons were presented to the experts in random order to maintain their engagement in the exercise. In view of its size, the questionnaire was administered on paper, formatted with the help of Excel, and posted to the experts. Experts were asked to reply in 28 days but this period lengthened because of the number of questions asked but the whole process was completed within the 45 days recommended practice [11]. The results were analysed in three ways – (i) negative to positive bipolar ranked assessment, (ii) bipolar sum of differences, and (iii) unipolar ranked assessment.

Results and analysis

All 13 experts participated in stage 1 but, presumably as a result of the lengthy questionnaire, only 11 participated in stage 2. Nevertheless, this number exceeds the minimum of 10 required for statistical significance [14] and the weightings presented below are therefore considered to be valid.

In stage 1 the experts' replies expanded the list of 15 initial criteria to 23 in round two, whereupon the adjusted list of criteria was administered again, using the same seven questions. In the third and final round, in response to the experts' suggestions the criteria were collected into three categories based on the life cycle stage(s) – installation, operation and end of life - to which the criteria relate. Additionally, two criteria two were merged, leading to the final 22 criteria (table 3 and 4).

Table 3 EPIM Assessment Criteria categorized according to their relevant life stage

<table>
<tr><th colspan="6">Energy Performance Improvement Measure (EPIM) Assessment Criteria (AC)</th></tr>
<tr><th colspan="2">AC result realised in the short term (beginning of EPIM's useful life)</th><th colspan="4">AC result realised in the long term
(i.e. during / end of EPIM's useful life)</th></tr>
<tr><th colspan="2">EPIM Installation</th><th colspan="2">EPIM Operation</th><th colspan="2">EPIM Disposal</th></tr>
<tr><td>1</td><td>Capital cost</td><td>9</td><td>Potential energy/carbon savings</td><td rowspan="11">20</td><td rowspan="11">Disposal cost of EPIM at end of useful life</td></tr>
<tr><td>2</td><td>Availability of grants, tax allowances and other financial incentives</td><td>10</td><td>Financial payback</td></tr>
<tr><td>3</td><td>Ease of installation of EPIM</td><td>11</td><td>Change to maintenance costs</td></tr>
<tr><td>4</td><td>Loss of significant, original building fabric</td><td>12</td><td>Ease of maintenance of EPIM</td></tr>
<tr><td>5</td><td>Requirement of planning and/or building control approvals</td><td>13</td><td>Reliability of EPIM's performance</td></tr>
<tr><td>6</td><td>Level of disruption to building occupants during works</td><td>14</td><td>Degradation of EPIM's performance</td></tr>
<tr><td>7</td><td>Impact on building's appearance</td><td>15</td><td>Training building occupants in the use of new system(s)</td></tr>
<tr><td rowspan="4">8</td><td rowspan="4">Impact on building's internal space/layout</td><td>16</td><td>Level of improvement in building occupants' comfort</td></tr>
<tr><td>17</td><td>Impact on existing building services</td></tr>
<tr><td>18</td><td>Impact on building's internal air movement/ ventilation</td></tr>
<tr><td>19</td><td>Impact on building's vapour permeability/ breathability</td></tr>
<tr><td>21</td><td colspan="5">Embodied energy/carbon of EPIM</td></tr>
<tr><td>22</td><td colspan="5">Environmental impact of EPIM</td></tr>
</table>

Table 4 Definitions of EPIM assessment criteria

No.	Assessment criterion	Definition
1	Capital cost	Initial cost incurred to purchase the EPIM, including all associated transport, labour and materials.
2	Availability of grants, tax allowances and other financial incentives	The availability of financial incentives for the implementation of particular EPIM's.
3	Ease of installation of EPIM	Also known as 'buildability'. The level of difficulty associated with the installation of an EPIM, including ease of transport to and movement on site.
4	Loss of significant original building fabric	Some EPIM's installation will have a low visual impact but may result in loss of significant, original building fabric.
5	Requirement of planning and/or building control approvals	The likelihood of requiring some form of formal approval for the installation of an EPIM, including Listed Building Consent where applicable.
6	Level of disruption to building occupants during works	The level of disruption caused by the installation of an EPIM on the building occupants' working environment, and consequently their productivity.
7	Impact on building's appearance	The impact the installation of an EPIM will have upon a building's appearance, both externally and internally.
8	Impact on building's internal space/layout	The installation of some EPIM's could impact upon the gross internal floor area or the internal layout of the building.
9	Potential energy/carbon savings	A quantitative measure of the energy savings and associated carbon emission savings of installing an EPIM.
10	Financial payback	A measure of the time required to recover the initial cost invested.
11	Change to maintenance costs	A potential increase or decrease in the building user's maintenance budget due to the installation of an EPIM.
12	Ease of maintenance of EPIM	The level of difficulty associated with the maintenance of an EPIM and any associated equipment or materials. Including the availability of spare parts over the lifetime of the EPIM.
13	Reliability of EPIM's performance	The reliability of an EPIM's performance. Risk of failure in meeting predicted energy savings, as well as any other performance criteria.
14	Degradation of EPIM's performance	The potential year on year reduction in the EPIM's ability to deliver energy savings.
15	Training building occupants in the use of new system(s) post refurbishment	The level of training and regular re-training required of building occupants to ensure the EPIM is operated at its maximum efficiency.
16	Level of improvement in building occupants' comfort	The level of improvement in indoor environmental quality due to EPIM installation, consequently improving the building occupants' comfort levels and potentially, worker productivity.
17	Impact on existing building services	The impact the EPIM's installation will have upon the existing building services (BS), including building fabric improvements, as these will change the internal environment and how it interacts with the BS. Some BS-related EPIM's can have a negative impact on the existing plant and its maintenance, and this must be considered.
18	Impact on building's internal air movement/ventilation	The impact of the EPIM's installation on how the existing building deals with air movement. A negative impact could lead to serious air quality and condensation issues. Also, whether changes to the building's ventilation strategy need to be considered as a result of this EPIM.

19	Impact on building's vapour permeability/'breathability	A qualitative measure of the impact an EPIM's installation has on the building fabric and how it interacts with moisture. Whether or not that EPIM is compatible with the existing construction form.
20	Disposal cost of EPIM at end of useful life	The financial cost of removing and disposing of the EPIM and any associated parts at the end of their useful life.
21	Embodied energy/carbon of EPIM	The total energy/carbon inputs required to manufacture an EPIM and its associated materials, from extraction of raw materials to reuse/recycle/disposal. This also covers the issue of EPIM availability, in terms of the energy/carbon cost of sourcing and transport.
22	Environmental impact of EPIM	The level of pollutants/environmental cost accumulated in the manufacture of an EPIM and its associated materials, from extraction of raw materials to reuse/recycle/disposal.

The results of the paired comparison questionnaire were analysed in three ways. In the negative to positive bipolar ranked assessment, the 9 point scale (table 2) essentially represents two opposing poles with a central point denoting equal importance. The scores obtained by a criterion in each of 21 comparisons with the other criteria are summed and the total score can therefore range from +84, denoting an overwhelmingly important criterion, to -84, denoting the reverse. In practice, most but not all of this range was used. In the bipolar sum of differences analysis, the criterion of lesser importance in each pair is scored zero instead of the negative value. This avoids over-emphasising the negative view of the less important criterion, and truncates the total score range to 0 to +84. The option of equal importance remains, with both criteria scoring zero. This analysis is considered to be the most appropriate for this investigation. Finally, the unipolar ranked assessment ascribes one pole in each pair as being more important, and can be viewed as a less natural fit with the paired comparison approach, despite having been used in this way previously [17]. In this case the total score can range from +21 to +189.

In each analysis, the total score gained by each criterion was averaged over all the 11 experts, and the mean values normalised to enable them to be presented as weightings in percentages. Table 5 shows the resulting scores for each criterion, and it is clear that the top five criteria in each case are the same and appear in the same order, and that the unipolar analysis gives a narrower distribution of values than the two bipolar methods.

As can be clearly seen in Figure 1, the criteria fall into three clear groups according to their weightings – a group of low importance assigned 2-3%, a group of medium importance assigned 4.5±1% and a group of high importance assigned 8±1%.

Discussion

The assessment criteria are largely self-explanatory but some comments may be helpful. It can be seen from tables 3 and 4 that the criteria for each EPIM are framed in neutral terms, such as ‘impact on …’ or ‘level of …’, to avoid prejudicing the experts’ comparisons. However, since the objective of an EPIM is to save energy and reduce carbon emissions criterion 9 was framed explicitly as ‘potential energy / carbon savings’. The word ‘significant’ is included in criterion 4 because it discourages the user from being too cautious and rejecting a beneficial EPIM because of the loss of fabric that would not be considered important in heritage conservation terms. In some cases, separate criteria were merged when it became obvious that, for example, payback period and financial savings are essentially equivalent, leading to criterion 10 ‘financial payback’, but are, however, unconnected with maintenance costs, thus retaining criterion 11 ‘change to maintenance costs’.

Figure 1 shows that three criteria - capital cost, potential energy / carbon savings and financial payback - are assigned the highest importance within the set. Since the objective of any energy improvement measure is to save energy and reduce carbon emissions within a business context, it is not surprising that these are the top three criteria. It confirms the experts’ pragmatic view that the typical user of the decision support tool is concerned with the financial impact of their decision on their organization. However, the fact that there are a further 19 criteria, together accounting for over 70% of the weighting scores, shows that they believe that decision making should be informed by much more than these three fundamental factors.

Table 5 Comparison of weightings (%) of the three analyses

Number	Criterion	Bipolar negative	Bipolar sum of differences	Unipolar
1	Capital cost	9.03	9.30	5.66
2	Availability of grant, etc	3.61	3.64	4.31
3	Ease of installation	2.50	2.42	4.04
4	Loss of significant building fabric	5.21	5.35	4.71
5	Requires planning approvals	1.83	2.56	3.87
6	Level of disruption to occupants	2.27	2.82	3.98
7	Impact on appearance	4.80	4.93	4.61
8	Impact on internal layout /space	4.93	5.22	4.64
9	Potential energy savings	8.79	8.77	5.60
10	Financial payback	8.31	8.22	5.48
11	Change in maintenance costs	2.86	2.87	4.13
12	Ease of maintenance of EPIM	2.53	2.27	4.05
13	Reliability of EPIM	5.67	4.85	4.82
14	Degradation of EPIM	4.48	3.77	4.53
15	Training of occupants in new systems	0.95	2.82	3.66
16	Level of improvement in comfort	4.55	4.48	4.55
17	Impact on existing building services	2.89	2.48	4.14
18	Impact on internal air movement	6.09	5.45	4.93
19	Impact on vapour permeability	7.49	7.19	5.27
20	Disposal cost of EPIM	2.00	2.08	3.92
21	Embodied energy of EPIM	4.32	4.22	4.49
22	Environmental impact of EPIM	4.90	4.30	4.63
	Total	100.00	100.00	100.00

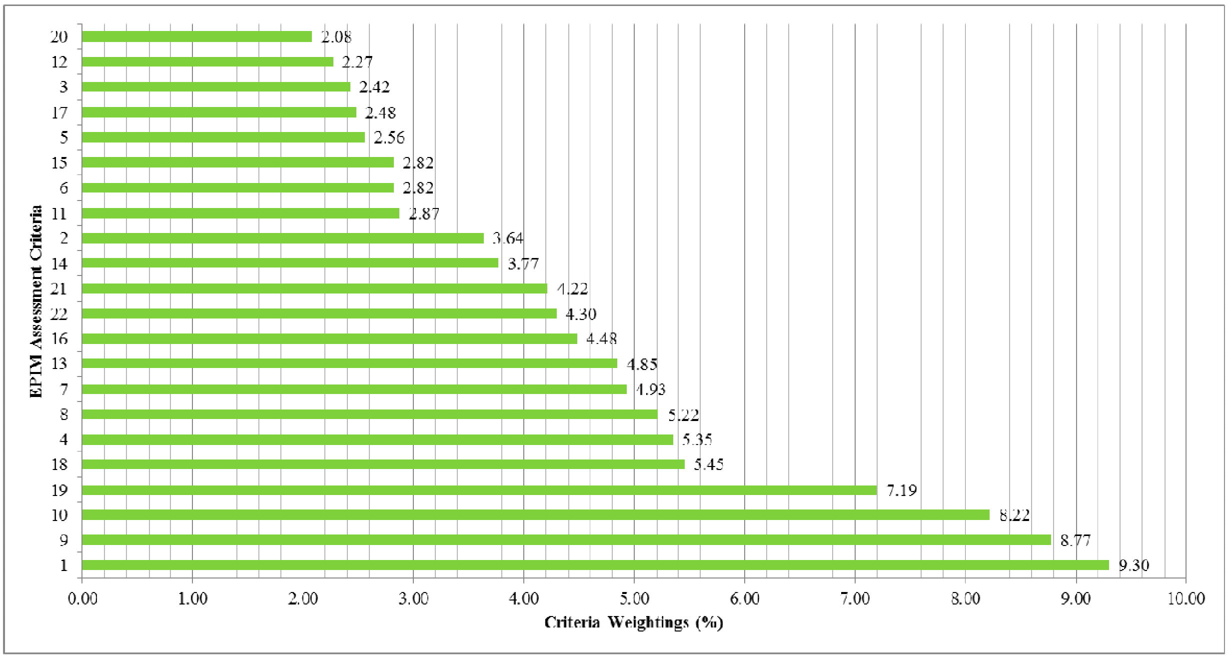

Figure 1 Criterion weightings obtained from bipolar sum of differences analysis

The prominence given to criterion 19 'impact on building's vapour permeability' is unexpected because this is a very technical attribute of an EPIM. It can be explained because it is a key feature of the traditional form of construction that the survey has targeted. Traditional buildings are known to be more complex in the way in which the building fabric manages moisture, as compared to modern impermeable construction forms [18]. Therefore, any EPIM that directly impacts the building fabric and how it interacts with the environment could have a detrimental effect upon the original building, as well as reducing the EPIM's performance, if it is not compatible with or not appropriately applied to the traditional construction form. One expert stated "...traditional buildings enable moisture to move through their fabric, get that wrong and you get an impervious building that gets damp and rotten quickly". Therefore criterion 19 essentially represents the EPIM's suitability for the construction form undergoing improvement. It would be interesting to see how highly this criterion would have been weighted if the assessment criteria were designed to address an existing building of modern construction.

The contrast between the importance placed on the fabric and the services is quite marked. Criterion 17 'impact on existing building services' is weighted lowly (position 19 in the rank order) whereas criteria 19 and 4 clearly relate to the effect of an EPIM on the building fabric, and are ranked in the top 6. This could again be due to the focus of this survey on traditional construction, and the more complex behaviour of the fabric than in modern construction.

Of the criteria with low weightings, numbers 3 and 12 concern the ease of installation and maintenance of the EPIM, respectively. The low importance is probably because these works would most likely be carried out by external contractors and therefore the risks are passed on to them. Cost of disposal of the EPIM at the end of its life (criterion 20) is considered relevant but of low importance, perhaps because this is a cost to be borne in the future. Disruption to the occupants during installation (criterion 6) can be managed by working out of hours, and training the occupants in the use of the new systems (criterion 15) is possibly less important when handing over a refurbished traditional building than when first occupying a new low-energy building.

Space precludes a detailed examination of the different perspectives of the experts, but it is clear that, while all the experts weighted capital cost, financial payback, potential energy savings and impact on the vapour permeability of the building fabric highly, those with a heritage focus also weighted loss of significant fabric and impact on appearance highly. Reliability of the EPIM was weighted the same but less highly by all experts. Experts with a client focus weighted internal comfort, existing services and impact on internal air movement more highly than other expert groups.

Conclusions

A crucial step in energy-led refurbishment of buildings is the multiple criteria decision-making process that must be applied to individual energy performance improvement measures. A Delphi survey identified 22 criteria, covering the installation, operation and disposal stages of the life-cycle against which such decisions are made. Pairwise comparisons using an group of experts enable weightings of the relative importance to be assigned to each criterion, and this can be used by decision-makers to score the refurbishment options in terms of appropriateness to their own building.

The Delphi technique is suitable for this purpose. However, whilst an expert survey with 13 respondents is statistically acceptable, a larger group would have been preferable and should be targeted in any future work. Further work should investigate how the relative weightings vary between expert groups with different perspectives and should extend the study to residential refurbishment.

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Session

Monitoring

Simulation Assistance and Data Analysis for the Performance Evaluation of Buildings

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Abstract

Modern, low-energy office buildings are a composition of several advanced constructions and systems. Energy efficiency of internal units such as lighting and HVAC depends on the building operation controlled by a management system. The control of several components is usually integrated into a system connected with several detectors and user control devices. On the other hand the user behavior is a crucial factor determining energy efficiency and affecting the optimal control algorithm. Useful information for calibration of the control system can be achieved from measurements as well as from a building performance simulation. The present paper explores the analysis of building energy performance by an ESP-r based simulation approach. An evaluation of the simulation results was made in an open source energy monitoring software, by comparing the measured energy data with the simulation output. A demonstration of the case study was made by the Lodz University of Technology by using an office building of the university as testbed.

Introduction

Aside from long-established building systems such as lighting and HVAC, low-energy buildings are equipped with additional systems for the controlling and generation of energy. The spectrum of modern building technologies is wide and covers automated control systems for HVAC and energy generation system for instance photo-voltaic systems or more modern methods such as geothermal system and the thermal activation of building structures. The combination of technical entities in modern office buildings form a significantly higher complexity, where the single processes influences other processes in a hardly comprehensible interplay. In addition to the technical influences, the users of the building may have adverse effect on the energy performance. Especially if energy efficiency concepts do not include the behavior of the building users, measures do not achieve the desired energy saving. A practical example for such an interference is an architectural lighting concept, where the reduction of the energy demand is based on a transparent interior design with glass elements to increase the usage from light sources. If the users are not well informed, they will not take into account the significance of the concept and unconsciously work against the approach, for instance by sticking posters on the glass walls or by placing a bookcase in front of it. To make complex buildings with all its technical and operational facets manageable, instruments providing a better understanding of the interacting systems become essential for the analysis and optimization of the energy efficiency performance in building operation.

The demand for assisting instruments directly leads to an increasing market for energy monitoring software, providing tools to enable the facility manager to make the energy consumptions and operating states visible and allow reactions on misbehaviors on the one hand, and providing a reliable data basis for economical decisions, for instance the retrofitting of technical systems. The monitoring of the building operation based on pure measured data allows the detection of anomalies from the common building operation by the comparison of current data with prior data readings. Additionally, monitoring software allows to directly display the effect of changing operating parameters or by changing the type of use. Nevertheless, the monitoring of sensor data only allows the analysis of variance referring to historical states, but not referred to the ideal operating point. To identify the optimal operating state as a reference value for the validation, dynamic simulation tools allow the analysis of the building performance with a specified precision through the definition of appropriate time and space discretization. The model definition can be done with a different level of accuracy by reducing a number of thermal zones and building components. Due to limitations resulting from computing capabilities, a model design has to strike the balance between accuracy and computing time in accordance with the application requirements.

In the following, the paper describes the determination of the energy performance of a building, based on a case study which explores two models of the same building, both defined in the open source software ESP-r.[1] The first model was characterized by simplified one zone geometry of the whole building and was used for the evaluation of overall parameters of energy efficiency. Through the precise definition of individual rooms, external and internal constructions and the airflow network for one story of the building under consideration, a more detailed analysis was conducted using the second model. The verification of the results were made by the comparison with real measured data using the open source energy monitoring software JEVis.[2]

Model description

Detailed model

In a detailed building model for energy performance simulation all existing zones are defined separately with detailed information about building components such as internal and external, opaque and transparent partitions. Moreover, zone characteristic including internal heat gains, air flow rate and system control, can be implemented in the model with accuracy reflecting real performance of the building.

Since a building simulation model is supposed to reflect real existing building performance it is necessary to provide all significant information that can affect simulation results. The accuracy of a model is not only about spatial discretization. Properties of a building materials and complexity of construction should be also taken into account with high precision. Simultaneously, accuracy of air flow model and proper definition of thermal bridges and air leakages have a high influence on building performance. Another aspect which can be considered only in a detailed model is the assumption of different occupancy profiles and temperature set points in specific zones.

That approach is desired when very detailed results are expected, and should be used with a high precision to avoid overestimation of the impact of some detail process on the general performance of the building.

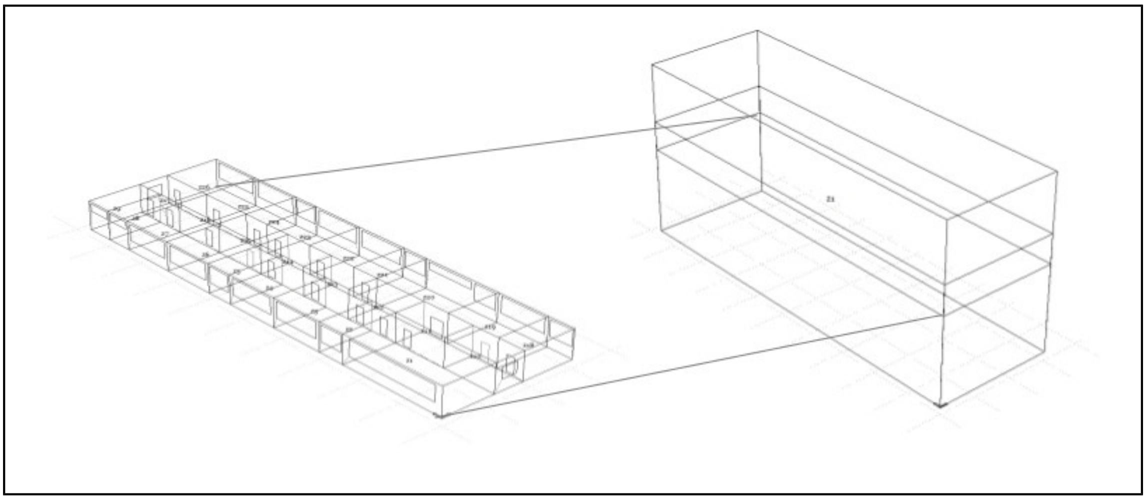

Figure 1: Detailed model of the building

In this paper, a detailed model one floor of the building is introduced and similar thermal conditions are assumed under and behind the considered floor. It was also assumed that windows in a specific zone will be presented as a one window with an equivalent surface.

General model

In a general building model all internal zones are treated as a one. A general model of a building can be used for overall energy performance evaluation. Assumption of a one zone model and lack of internal walls imply a significant decrease of the thermal mass of the building and totally neglects the real construction of internal partitions. Moreover, that approach does not take into account different functions of individual areas, different occupancy profiles and heating loads. User characteristics for toilets, corridors and staircases interfere overall performance, and obtained results cannot be averaged for a specific floor surface. Approximating the building by the one zone makes it impossible to access the conditions in a single office room, due to the fact that the whole building is treated as one room.

Generalization of building model causes neglection of construction thermal bridges, especially linear one's. In that model it is also impossible to simulate in detail the airflow inside the building and leakage of the air through the window and door cracks. It can also be noted that solar heat gains by one surface can be transferred directly to the opposite external surface which can highly affect heat exchange processes on the considered surfaces.

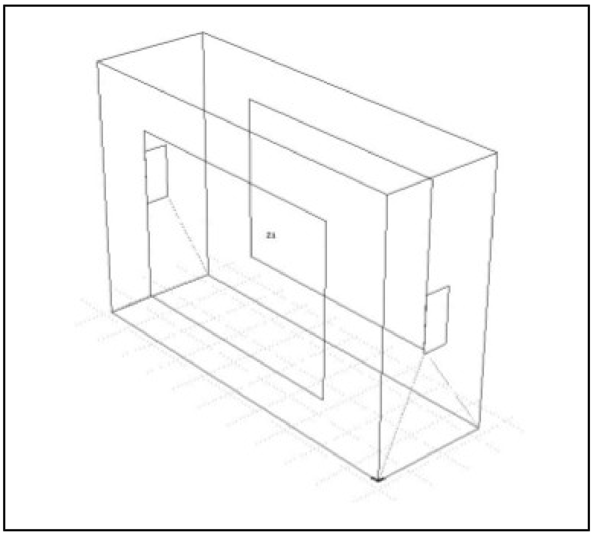

Figure 2: General model of the building

In that model the ventilation rate is assumed from standards, for instance 20 m³/h*Person for office rooms and can be optionally re-configured if a more precise value is available. To take the efficiency factor of the heating system into account, the factor is assumed from statistic value depending on the system type and the manufacturing year.

Comparison between two models

Building simulation can provide a cost efficient and quick method to evaluate buildings and their components performance [3]. Nevertheless the complexity of the model is crucial for accuracy of simulation results. The level of a model's precision determines the amount of information that can be obtained from simulation. By proper representation of subsequent informations more detailed processes can be analyzed. Therefore the amount of data introduced into the model should reflect the expected outcome and be suitable for a specific application. Generation of a completely precise model requires a huge number of input data.

In this paper, the authors made a comparison of two building models with different levels of input data accuracy. Analysis showed that most of the results obtained for the detailed model cannot be defined for general model. Evaluation of energy performance of the building can be achieved for both models simultaneously with different level of accuracy. In the general model it is estimated only on a basis of heating energy demands, while for the detailed model the following values can be also taking into account:

- total heating loads in a specific zone,
- air temperature in the zone,
- temperature of internal and external opaque surface,
- temperature of internal and external transparent surface,
- heat flux by conduction through surface.

Moreover, the simulation gives the possibility to estimate additional parameters which are very problematic or impossible to be measured empirically, as:

- solar heat gains by a specific surface to the zone,
- resultant temperature,
- infiltration zone flux,
- internal heat gains.

Case study

Geometry

The analysis and simulations were performed for a real existing 9-storey, university building located in Central Europe (moderate climatic conditions). The main part of the building consists of 8 floors with offices and classrooms, and additional technical floors on the basement and top level. Each floor has a corridor layout, rectangular shape with 48 m length and 15.3 m width.

Figure 3: Analyzed university building Construction

The building considered in the analysis is constructed from concrete wireframe with pillars at a distance of 3 m. The curtain wall consists of opaque and transparent parts that fill the space between the pillars. The ceiling is constructed of channel plate. Internal walls are made from brick while external one was made from porous concrete insulated by 0.1 m layer of expanded polystyrene. Thermal transmittance of external opaque envelope is 0.35 W/m^{2}K and of transparent part 1.1 W/m^{2}K.

Operation

In the detailed simulation model internal heat gains and ventilation rate should be defined with the greatest possible accuracy. Due to highly irregular presence of people in the university building it was difficult to specify precise values of gains and losses caused by occupancy profiles. It was assumed that heat gains from each person are at the level of 115 W (80% of which was sensible heat and 20% latent). Additionally, a computer set generates 125 W of heat. The ventilation flow rate was defined as 1.3 ACH (office) and 8.3 ACH (classroom) during heating season. Considering the fact of possible increase of the air flow by opening the windows, ventilation rate was defined differently during winter (1.3 ACH) and summer season (10.0 ACH). Heat gains from lighting were taken into account during the period of time when illuminance from natural light is insufficient. It means that heat gains from the artificial lighting change during the year, with the highest value defined during winter.

The number of people changes from 1 to 2 for offices and 15 to 30 for classrooms depending on the size of the zone. It was assumed that office rooms are occupied 8 hours from Monday to Friday, while classrooms only half of that time. Analysis was conducted for the whole year with the assumption of heating season from October to May. Indoor air temperature was controlled during the heating season with a set point of 20°C. For the rest of the year the heating system was turned off.

Results

Energy

Energy demand for heating was calculated for both: detailed and general model. Obtained results for the whole year are shown in Figure 4. It can be noted that energy demand for heating is similar for the coldest winter months in both models. On the other hand, differences in results are significant during March and October due to the higher solar irradiation and temperature differences between day and night. In the general building model the effect of solar heat gains utilization is partially neglected. Simultaneously, estimation of the energy demands in a specific part of the building can be obtained only using the detailed model.

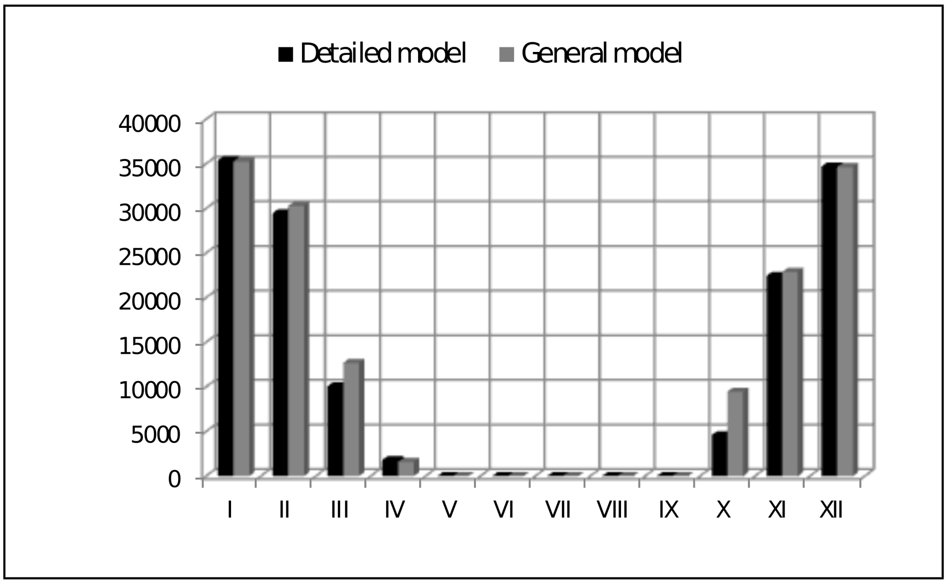

Figure 4: Energy demand for heating for detailed and general models.

Heating Energy Demands of Single Rooms

Analysis of results from the detailed model allows to evaluate more physical parameters, such as room air and surface temperatures, energy loads or heat fluxes for all zones under consideration. Exemplary results for selected two zones that differed in occupancy profiles, single office and large classroom, are presented in the graphical form (Fig. 5 and 6). In Figure 5 the monthly energy demand (sensible and latent) for selected zones are presented. Results obtained for both zones are comparable for winter months, but during March, April and October differences are significantly greater.

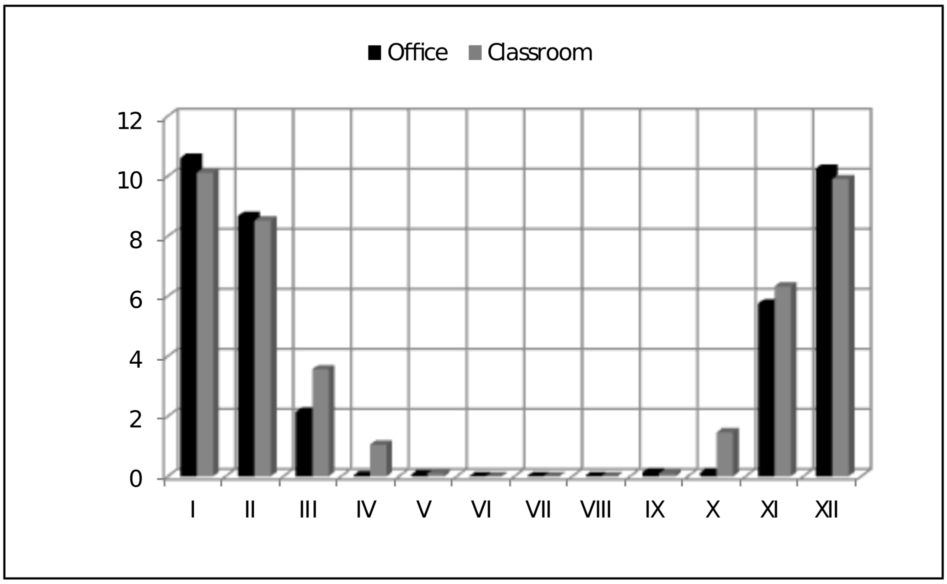

Figure 5: Heating energy demands in analyzed zones

Temperature

In Figure 6 air temperature versus time in analyzed zones during a typical week of summer is shown in the top. It can be noted that the temperature in the analyzed zones is very high and rises up to more than 40ºC. On the other hand, in the middle of the day it decreases to 25ºC. These temporary decreases of air temperature during occupancy time correspond to higher ventilation rate. In winter, air temperature is constant as an effect of an assumed air heating system that maintained the temperature at 20ºC.

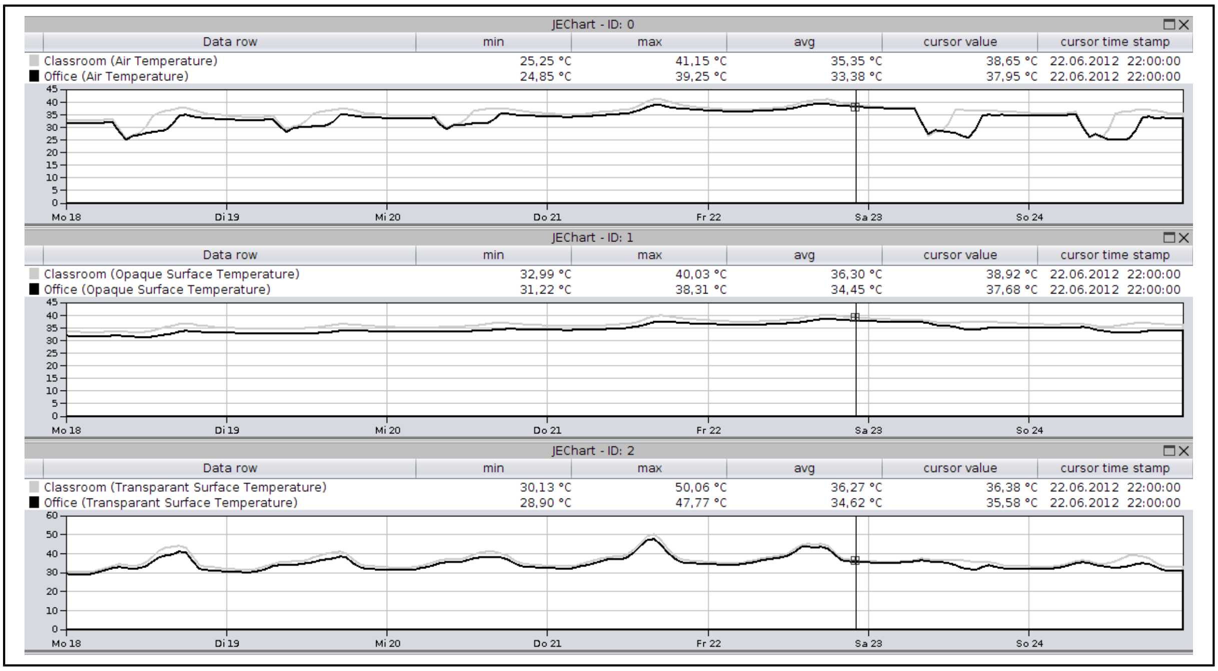

Figure 6: Air temperature in analyzed zones during selected week in June.

The chart located in the middle of Figures 6 shows the temperature of the internal opaque surface of the external wall in the analyzed zones in a selected week in summer. On that basis it can be evaluated which type of room is more sensitive to the external environment. Comparison between surface and air temperatures shows the additional effect of thermal inertia of building components. It means that during the period of increased ventilation rate temperature changes on the surface do not reflect air temperature fluctuation.

The surface temperature of the transparent components is presented in the bottom of Figure 6 for a summer week. In that case, the temperature values were dominated by the influence of the solar radiation absorbed in the glass pane and the effect of indoor air temperature is less significant. Moreover, temperatures of transparent surface are higher than of opaque during the day and lower during the night. It can also be noticed that temperatures of transparent surfaces for both zones are comparable. An additional result that can be calculated using the detailed model is the heat flux by conduction through the surface. Such detailed results allow to estimate the effect of heat losses by conduction in the total balance of heat loads. This parameter can be easily validated by in-situ measurement, while the ventilation heat flux rate is very difficult to be measured.

Energy Monitoring Tool

The verification of simulated energy performance is studied by connecting the ESP-r simulation results to an energy monitoring software, enabling the comparison with the metered energy consumption of the building. By connecting the simulation tool to the energy monitoring tool, the performance of the building is no longer evaluated only on historical references but also with simulated reference values by using common instruments of analysis.

The used monitoring software JEVis is a software system for automated data acquisition, processing and visualization former developed by the company Envidatec GmbH together with the Institute of Computer Technology at Vienna University of Technology. Currently it is being further developed in the open source project OpenJEVis, driven by partners from the academic and industrial sector. The project sees itself as a booster for research and development cooperations, promoting a free solution which takes the interests of the members and their needs into account. The GPL licensing allows the realization of systems without license fees and ensures the feedback of developments into the project [4].

The JEVis software system provides a classical client-server architecture and integrates different protocols and technologies into one database by providing a common abstraction layer. It is implemented in the object oriented programming language Java and is based on and uses open source components such as the HTTP web server Tomcat that allows to run Java code, the relational database MySQL, and GNU Octave for numerical computations. JEVis provides functionality such as automatic data fetching from several data sources, boundary testing with hard and soft fails to detect and avoid invalid data samples, snap to grid functionality to modify the sampling time, unit conversion, data aggregation, GNU Octave integration for custom calculations and an open documented Simple Object Access Protocol (SOAP) web service functionality. These offered services can be interfaced with SOAP by any compatible application in a machine-readable presentation to provide a vendor independent data exchange. The data structure can be created freely to one's needs. However, it is advised to map the structure of the installation into the JEVis registry. If different representations are necessary, these can be created by creating shadow structures that consist only of links to the original data. JEVis provides various methods to interface and import data, such as File Transfer Protocol (FTP), Hyper Text Transport Protocol (HTTP) and OPC. JEVis is multi-platform due to its Java source [5].

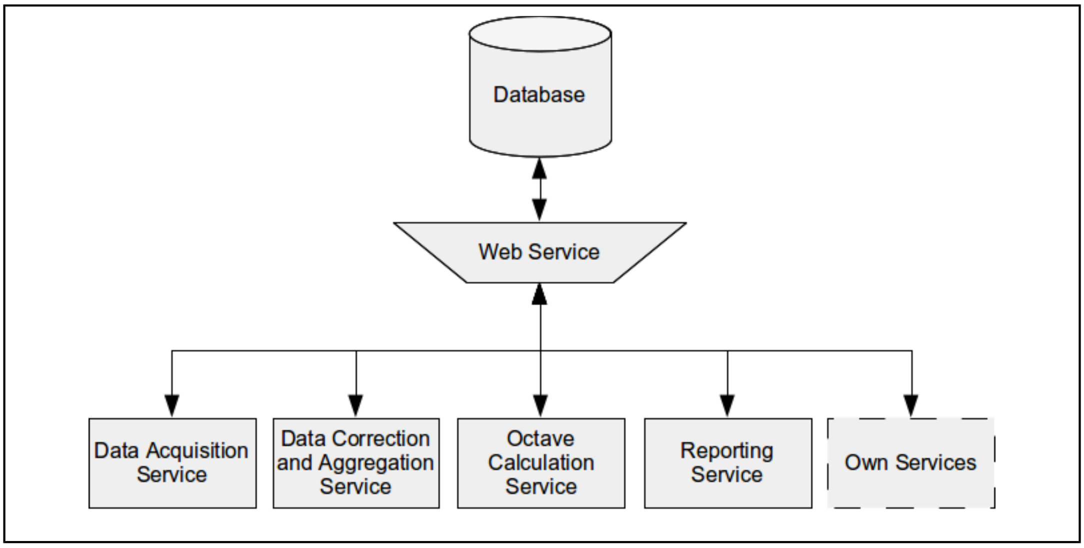

Figure 7: Overview on the monitoring system architecture

Regardless of the chosen programming language, the web service allows the interaction with the JEVis database. Through the web service, it is possible with any conventional web technologies such as Hypertext Markup Language (HTML) or PHP to access the managed data. Data may be freely integrated and visualized in this way in web pages.

Additionally, third-party added value tools are available for JEVis. For the continuous monitoring of results in the testbed in Lodz, the program JEGraph for the visualization of energy and operating data is used for the graphical analysis. JEGraph offers a clear display of data curves and also integrates more display options, such as tabular views, graphical benchmarks and location information. The various display options can be combined and can be saved as analyses. The program was developed by Envidatec exclusively for accessing data in JEVis systems. JEGraph is available for free for non-commercial use at home or in the field of education and research [6].

Analysis of Building Performance Assisted by Simulation Results in JEVis

For the analysis of the building performance assisted by simulation results, ESP-r was connected to the monitoring tool by importing the output of the simulation via the central web service into the JEVis database, where both simulation data and metered data are stored in one structure.ESP-r provides the possibility to define own text-based output file format, enabling the manual or automated import of the output data into the JEVis system.[7] For the direct import of the ESP-r results, a simple shell script was created, executing ESP-r and pushing the data from the output file into the database by using the JEVis command line tool JEDImpEx (JEVis Data Import Export). For the analysis of simulated data, different calculations were made to enable an automated indication of differences, the creation of energy performance indicators, and the detection of characteristics between simulation and metering.

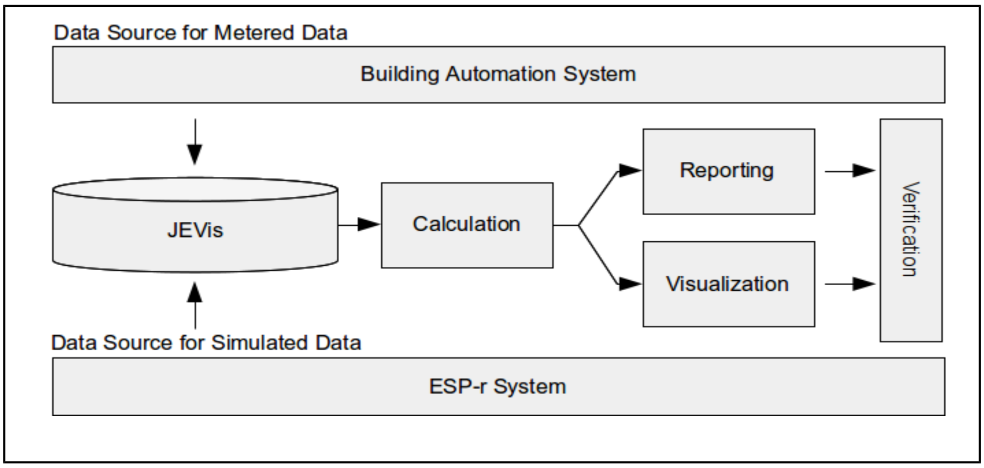

Figure 8: Scheme of the analysis structure

Expanding existing energy monitoring systems with simulation-based analysis leads to an integrated solution that assists both the operator of a building in its daily work being responsible for the efficient operation as well as the investor during the planning process of building modernization. A demonstration of a combined energy monitoring system is installed in a building of the Lodz University of Technology, being used for the calibration of simulation models and the analysis of anomalies as well. After the successful calibration of the simulation models, the models will provide a useful base for the benchmarking and rating of energy performance and the effect of energy efficiency measures in the building operation. The results will lead to the finding of potential energy savings achieved by low-invest measures, for instance by finding and fixing misbehaviors and suboptimal parameters settings which always have existed, and thus cannot be found by the monitoring based on historical data. Also high-invest measures such as the retrofitting of existing systems will be simulated and evaluated by using the integrated monitoring solutions. The detailed analysis of the expected impact and the comparison with the later metered data will additionally refine the simulation models and will help to forecast the energy savings by new technologies in a higher accurateness. After finishing the current calibrations, the equipped university building will be used within the collaborate research project “German-Polish Energy Efficiency Project” (GPEE) as a testbed to evaluate new façade technologies.[8] The further standardization of the interaction of the developed simulation tools with the energy monitoring tools, enabling a distribution which is applicable for a wide range of buildings, is an important step for the utilization of the results in daily applications.

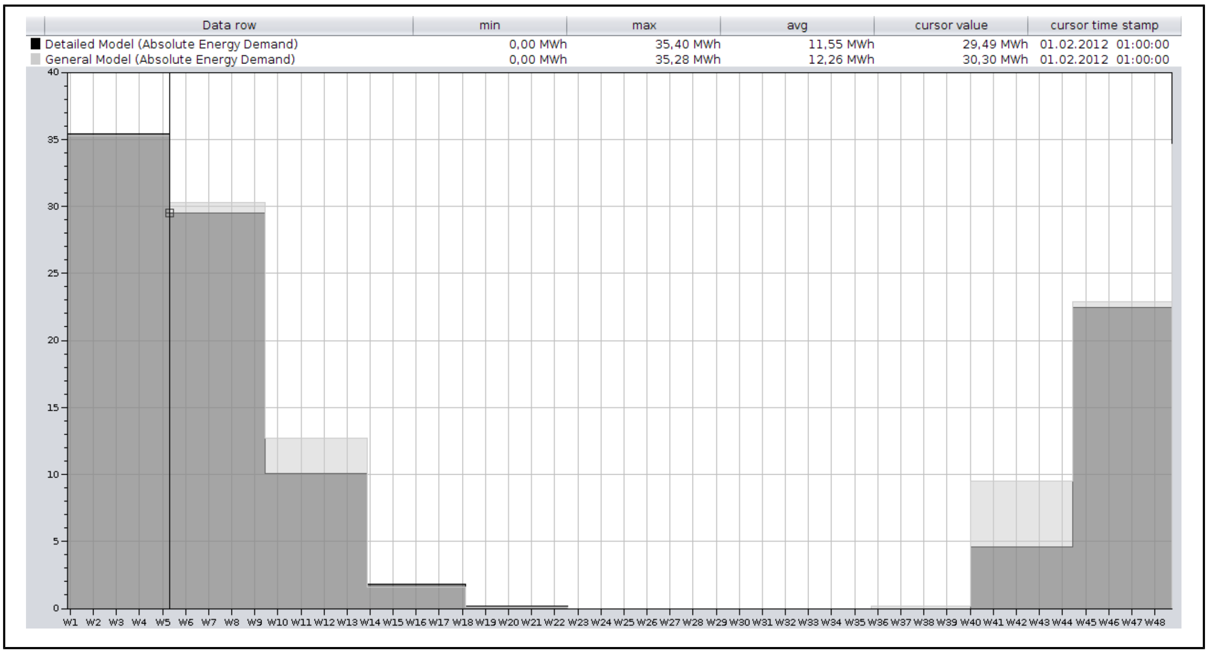

Figure 9: JEGraph analysis of the annual heating energy demand of the test building simulated by the detailed and the general model

Conclusion

By connecting metered building data and simulation results into an energy monitoring software, additional benefits for building owner and operator can be provided. Generalized models can especially be used for a fast energy baseline estimation, for instance as a basis for the creation of energy performance indicators. Additionally, generalized simulation models can be used to roughly estimate the energy demands of a multitude of buildings with a minimal manual effort. Detailed simulation models, providing more precise information into the monitoring software can be used especially in the planning phase of new investments. Based on the results of a detailed simulation, different material and equipment setups can be calculated which allows a more reliable information basis for the proofing of energy efficiency measures. By having the calculated results in the central energy monitoring tool, the measure can be monitored after the implementation based on expected impacts from the simulation.

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Study on the Database for Energy Consumption of Commercial Buildings (DECC)

Part 1: Release of the DECC on the web and development of standardized hourly energy consumption models for office buildings.

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Abstract

The Database for Energy Consumption of Commercial Buildings (DECC) is the first national energy consumption database in Japan. It consists of a basic database and a detailed database. The basic database stores monthly primary energy intensity data and the detailed database has data on hourly energy intensity as well as on end-use and heat source equipment.

Since release of the basic database on the web, about 2,500 downloads have been counted. Investigation of registered user data and questionnaire surveys with the download users indicated that the DECC was downloaded by various users such as facility engineers, researchers and building designers. They typically used it as a reference when they plan or design energy-saving measures.

As an example of utilization of the DECC detailed database, this paper describes the development of standardized hourly energy consumption models for office buildings after a brief introduction of the detailed database. The developed models are divided into three categories in terms of energy consumption (low, medium, high), and subdivided based on whether or not the building has a thermal storage unit. The models are expected to be utilized when planning or designing DHC plants and area-wide energy sharing networks.

1. Introduction

The building sector accounts for 40% of the world energy consumption[1]. Reduction of energy consumption and CO_2 emissions in the building sector is a very important task for every country. The fourth assessment report of the IPCC[2] pointed out that there is big potential for reducing energy consumption in the building sector. In order to formulate effective measures, reliable data for better understanding of the present situation are essential. In the USA, the Department Of Energy (DOE) surveys energy consumption every four years and publishes the Commercial Buildings Energy Consumption Survey (CBECS)[3]. The CBECS has been used as a reference in a variety of policy-making processes. The California Energy Commission and major utility companies provided the more detailed Commercial End-Use Survey (CEUS)[4]. In the EU, the ODYSSEE[5] database has been released and is available on the web. In IEA EBC Annex53[6], some online data collection systems and statistical analysis are described.

In Japan, the DECC Committee, which consists of 33 universities and some research institutes, was established in 2006 and conducted an energy consumption survey supported by the Ministry of Land, Infrastructure and Transport (MLIT) and energy suppliers. Since then, the DECC Committee conducted similar surveys for three times (2008, 2009,and 2011) and one more survey is ongoing. Overviews of the DECC were presented in previous papers[7][8]. The DECC basic database was released on the web in December 2010 and has been downloaded about 2,500 times. This paper presents an overview of the DECC basic database currently available on the web.

Once the databases have been released on the web, it is important to collect assessments and evaluations in order to improve the contents. The DECC Committee investigated DECC user data which was input at the time of download. It also conducted a questionnaire survey with DECC users who downloaded it. The results are described in this paper.

The released DECC database provides only a brief overview of statistical analysis. Basically, analyses and standardizations or utilization are left to users. CEUS provides estimated 16-day (weekday, weekend, hot day and cold day for each of four seasons) hourly end-use load profiles for 12 building uses. Hourly energy analysis is required for designing or planning an energy system in a building or District heating and cooling (DHC) plant. In Japan, the typical process of planning and designing energy plant for buildings or DHC plants is based on performance of an hourly energy consumption simulation for a representative day of each month throughout the year. A standardized hourly energy consumption model for the representative day of each month from the DECC can be very useful in real design and planning processes. As an example of utilization of the DECC detailed database, this paper describes the development of an hourly energy consumption models after a brief description of the DECC detailed database.

2. Overview of DECC

“DECC” is an acronym for “Database of Energy Consumption of Commercial Buildings.” There are two types of database in the DECC: basic and detailed. The basic database stores monthly primary energy intensity, which means primary energy consumption per floor area. The detailed database has data on hourly primary energy intensity for each end-use. Each database has the building property information shown in Table 1 as well as the energy related data shown in Table 2. In order to preserve building anonymity, floor area was expressed by category.

In December 2010, the DECC basic database was released on the web. Before the release, a screening test was performed to detect and remove outlier data. The test procedure was as follows.

(1) Building use, floor area or energy consumption: if a value was missing for any of these items, the data were removed.

(2) If the primary energy intensity was more than 10 times or less than 1/10 of the averaged value of each building use and region, the data were removed.

(3) The Smirnov-Grubbs test was performed with the significance level set at 0.05, and outliers were then removed.

As a result, the total number of buildings in the current release (December 2013) is 38,273. The number in each fiscal year is as follows: 2006 - 8,783, 2007 - 12,927, 2008 - 11,782, and 2010 - 4,781.

In 2011, a few months after the Great East Japan Earthquake and in a situation of power shortage, the DECC Committee conducted an urgent investigation about behavior related to saving electricity (especially at peak use time) as well as energy consumption. Since it was an urgent investigation, the data collection was limited to the buildings that had provided their energy consumption data before. This is why the data in 2010 data numbered less than half as many as in previous years. The analysis of energy consumption before and after the earthquake is reported in another paper[9].

Table 1 Building properties included in DECC

Stored data	Description
ID	Region(2 digits)+Building use(2 letters)+serial number(6 digits)
Region	Hokkaido, Tohoku, Hokushinetsu, Kanto, Chubu, Kansai, Chugoku and Shikoku, Kyushu
Use	Office, Information center, Public assembly, Department store and supermarket, Retail, Convenience store, Food service, Lodging, Health care, Welfare facility, Kindergarten and preschool, Elementary and junior high school, High school, Higher Education, Laboratory, Theater, Exhibition Facility, Sport Facility, Complex facility, Appliance stores, Large suburban store, Retail store, Barber shop, Other
Ownership and occupancy	Owner occupied or Nonowner occupied
Floor area category (exclude indoor parking)	Under 300m^2 More than 300m^2 and under 2,000m^2 More than 2,000m^2 and under 10,000m^2 More than 10,000m^2 and under 30,000m^2 More than 30,000m^2
Year of construction	Year
Number of floors	Number of ground floors and underground floors
Operating hours	Weekday, Saturday and Sunday [hours/day]
Term of air conditioning	Cooling starting and ending day Heating starting and ending day
Contract demand charge	Unit W/m^2 or VA/m^2

Table 2 Energy consumption data

Energy consumption data	Data type and unit
Year of data	Fiscal year (Apr.-Mar.)
Electricity consumption	kWh/m^2・year
City gas consumption	Class of city gas, m^3×10^{-3}/m^2・year
LPG consumption	m^3×10^{-3}/m^2・year or g/m^2・year
Oil consumption	Type of oil, little/m^2・year
DHC cold/hot water, steam	MJ/m^2・year
Primary energy intensity	MJ/m^2・year
Clean water consumption	m^3×0.001/m^2・year

Figure 1 shows the number of datasets for each building use stored in the released DECC. The data satisfy statistical significance in the case of most regions and building uses. Thanks to the cooperation of municipal boards of education, a large number of school data were available.

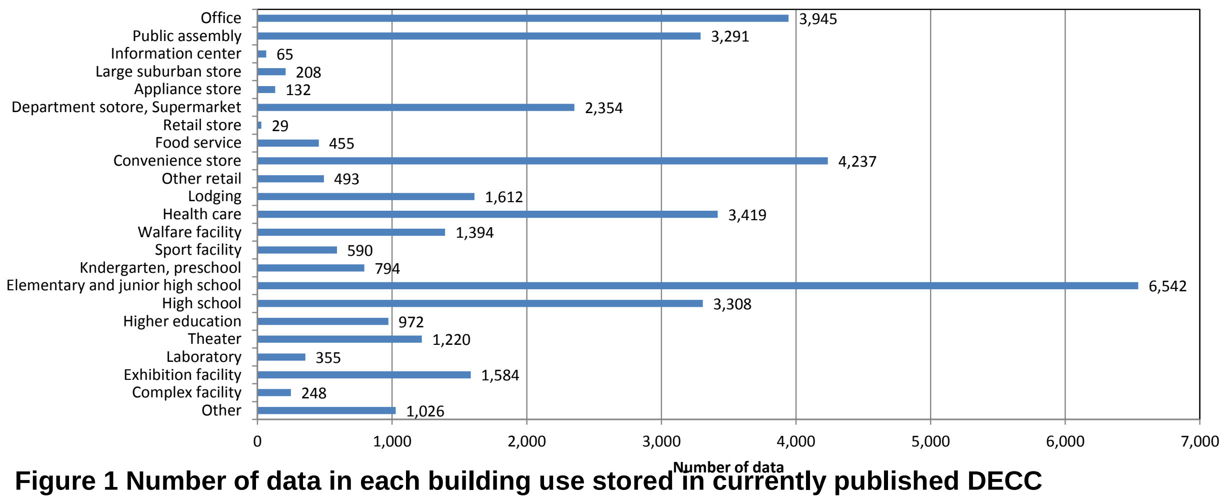

Figure 1 Number of data in each building use stored in currently published DECC

Figure 2 shows the distribution of primary energy intensity for each building use (FY2008). The number of data and average value of primary energy intensity are also shown below the graph. It should be noted that, in some building uses, the number of data is relatively small and statistical significance may not be satisfied, since Figure 2 shows a single year (FY2008) only. The values of primary energy intensity are very big for food services, convenience stores and information centers. Since convenience stores and information centers are operating 24 hours a day and have large energy consumption appliances such as IT servers and large refrigerators, their annual energy consumption is high. Since schools have long holidays, their annual energy consumption is relatively low. The average primary energy intensity for offices was 1,702MJ/m^2·year (473kWh/m^2·year) in FY2008..

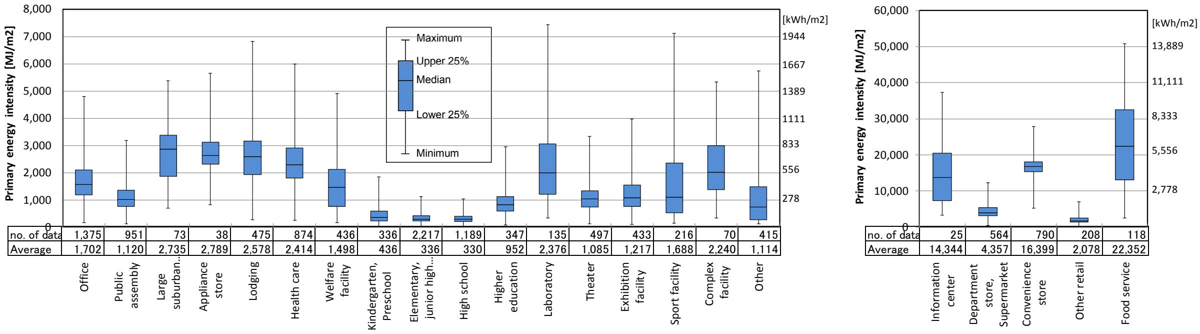

Figure 2 Distribution of primary energy intensity for each building use in FY2008

3. Users of DECC

3.1 Who downloaded DECC and why?

The DECC basic database has been downloaded 2,449 times since its release in December 2010. As it has been updated several times, many users downloaded it more than once. The number of registered DECC users is 1,851, which is consequently not the same as the number of downloads. To download the DECC, registration is necessary. Users are requested to provide some information such as their e-mail address and purpose of DECC use. Figure 3 shows user occupations, and Figure 4, purposes of DECC use with multiple responses allowed. These results suggest that many users use the DECC to obtain reference values for the design or planning of energy systems and energy-saving measures.

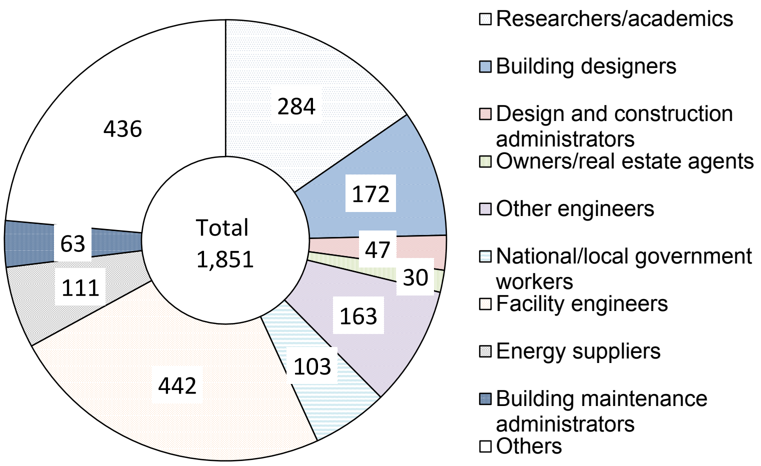

Figure 3 User occupations

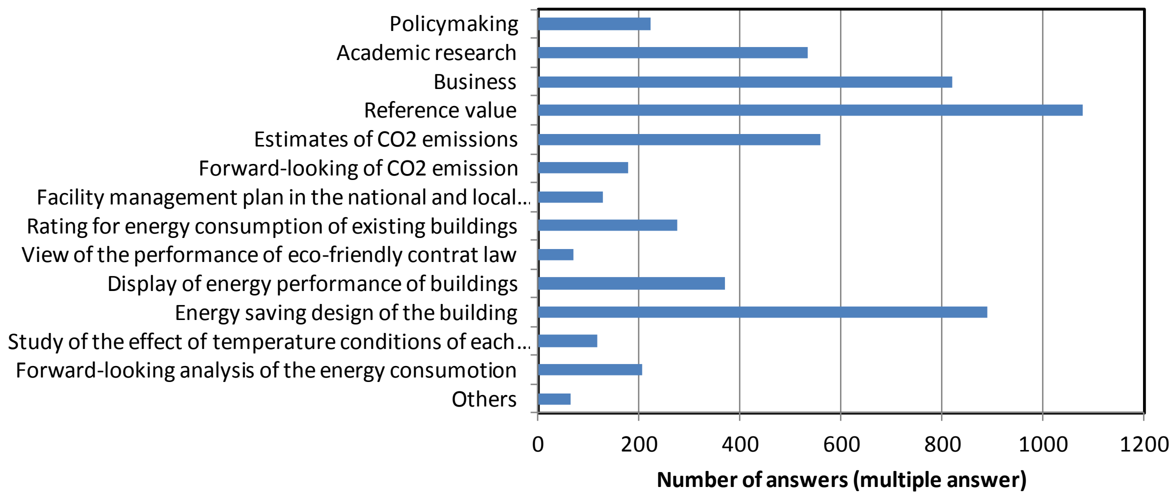

Figure 4 Purpose of using DECC (multiple answers allowed)

3.2 Questionnaire to DECC users

In the summer of 2012, a questionnaire was conducted with DECC users by the DECC Committee in order to learn how they utilize the DECC, their degree of satisfaction with it, and their requests for its improvement. The questionnaire was prepared on the web, and an e-mail requesting completion of the questionnaire was sent to each registered user. The number of effectively completed and returned questionnaires was 60. The results were as follows. The top answer to the question “How did you learn of the DECC?” was “the internet,” followed in order by “recommendation by other users” and “attended a DECC symposium”. This result suggested that more effective advertisement may be necessary for wider use of the DECC. Other results showed that most users were basically satisfied with the DECC.

The largest number of requests for improvement concerned an increase in the number of floor area categories. As described above, to preserve building anonymity, floor area wasn’t directly indicated but merely expressed in terms of the appropriate category. Initially, there were three categories of floor area: under 300m^2, more than 300m^2 and under 2,000 m^2, and more than 2,000. In response to these requests, the number was increased to five: under 300m^2, more than 300m^2 and under 2,000m^2, more than 2,000m^2 and under 10,000m^2, more than 10,000m^2 and under 30,000m^2, and more than 30,000m^2, as shown in Table 1.

4. Developing standardized hourly energy consumption models

Standardized hourly energy consumption models for office buildings were developed using the DECC detailed database, which stores hourly energy intensity data for each end-use. In the design or planning of DHC plants or area-wide energy sharing networks, an hourly energy consumption model is needed in order to determine the appropriate capacity of equipment and to optimize the network.

4.1 DECC detailed database

The DECC Committee collected BEMS (Building Energy Management System) data from buildings that had received subsidies for installing BEMS from NEDO (New Energy and Industrial Technology Development Organization). To collect data, a letter requesting provision of BEMS data to the DECC Committee jointly signed by the MLIT and the METI(Ministry of Economy, Trade and Industry) was mailed along with storage media (CD-R, DVD-R or USB memory). In the 2011 investigation, the reply rate was 41% and valid data were received for 121 buildings.

The format of collected data differed depending on the building or the BEMS. Therefore, it was necessary to put them in a uniform format. The data were arranged on a spreadsheet in which the vertical axis was time and the horizontal axis was measured or calculated energy consumption data. The vertical axis started from 00:00 on the 1st of April to 23:00 on the 31st of March in the following year (which is the fiscal year in Japan), in one-hour time intervals. If the BEMS data had smaller time intervals than one hour, the data were averaged on an hourly basis. For example, the datum at 23:00 on 31st March in the uniform format is the average value from 23:00 to just before 0:00. Measured or calculated values on the horizontal axis, which indicate energy consumption data for each end-use, varied depending on the building and are not easy to put into the uniform format. So far, the DECC Committee has determined some detailed levels of arrangements for end-use data. In this study, the end-use data arrangement shown in Table 3 was used.

Table 3 Detailed database uniformed format used in this study

Energy type	Electricity							
Primary energy consumption	Liting and plug load	Heat source	Heat source appliances	Heat convey	Package A/C	Air convey	Elevator escarator	Other
unit	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡

Energy type	City gas			Oil	
Primary energy consumption	Heat source	Package A/C	Other	Heat source	Other
unit	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡

Energy type	DHC		CGS or generator		
Primary energy consumption	Cold water	Steam or hot water	Energy consumption	Generated energy	Heat recovered
unit	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡	kJ/㎡

4.2 Standardized hourly energy consumption models

Standardized hourly energy consumption models were developed by using the DECC detailed database. In Japan, building energy consumption has changed since the Great East Japan Earthquake and the following power shortage. In this study, the DECC detailed database for FY2011 (April 2011 to March 2012) was used to incorporate the effects of energy-saving behavior (especially at peak use time) into the energy consumption models.

From the DECC detailed database, the study used data for 26 buildings in which office area accounted for more than 50% of the total floor area, and which were located in areas with a similar climate (i.e., the Kanto, Chubu and Kansai areas). When more than one month of data was missing, the data for the same months of the previous year (FY2010) was substituted with a correction coefficient. The correction coefficient was the ratio of FY2011 annual energy consumption to FY2010 excepting the months for which data were missing. Data deficits less than one month were ignored.

The average annual primary energy intensity of the 26 buildings was 1,785MJ/m2(496kWh/m2), which is almost the same level as in the basic database. Those buildings that have BEMS tend to be more conscious about energy conservation but also tend to be larger. As a result, the primary energy intensity approaches the general average value.

Standardized primary energy consumption models are hourly energy consumption patterns for representative weekdays, Saturdays and Sunday/holidays for each month. In order to develop them, the 26 buildings were categorized with reference to the monthly energy consumption pattern in the year. A cluster analysis was conducted using annual energy consumption and energy consumption in summer (July to September) and winter (December to February). As a result, 26 buildings were categorized in the three types shown in Table 4.

Table 4 Result of cluster analysis

Type	Pattern	Floor area [m²]	Built	Percentage of office [%]	Primary energy intensity [MJ/m²]		Heat source equipment															
					2010	2011	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	DHC
I	1	9,358	1988	100	1,189	1,105										x						
		6,133	1991	100	1,120	1,044									x			x				
		29,665	1969	100	1,694	1,336	x		x					x								
		7,099	1990	80	1,581	1,387										x						
		12,505	1992	91	1,518	1,159										x						
		19,115	1993	57	1,165	1,018												x			x	
	2	19,609	2004	100	1,915	1,334			x		x					x				x		
		5,034	1988	100	1,816	1,439					x									x		
		11,747	1985	70	1,445	1,334													x		x	
	Av.	13,363	1,989	89	1,494	1,317	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
II	3	25,462	1991	100	2,017	1,635										x						x
		34,516	1987	98	1,920	1,695	x	x	x	x					x							
		15,608	1992	58	1,750	1,721						x			x						x	
		9,638	1989	71	2,603	1,823										x					x	
		39,085	1992	99	1,923	1,500																x
	4	10,779	1991	100	2,145	1,771					x									x		
		11,886	1988	69	1,408	1,669					x									x		
		18,794	1976	55	2,163	1,590								x		x				x		
		90,270	1962	59	1,859	1,704	x							x	x	x	x	x		x		
	Av.	28,449	1,985	79	1,976	1,679	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
III	5	10,345	1993	50	3,010	2,757								x		x						
		21,723	1994	96	3,185	2,654				x						x						
		15,162	1989	85	3,605	2,581					x	x										
		164,293	1993	100	2,841	2,233		x														x
		183,063	1976	70	2,601	2,168																x
		130,199	1968	67	2,396	2,106										x						x
	6	43,136	1963	81	3,833	3,701			x										x			
		23,397	2003	61	2,218	1,950									x				x			
	Av.	73,915	1,985	76	2,961	2,519	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total av.		37,216	1,986	81	2,112	1,785	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

A:Steam boiler, B:Hot water boiler, C:Centrifugal chiller, D:Screw chiller, E:Air source heat pump (central)
F:Water source heat pump, G:Single effect absorption chiller, H:Double effect absorption chiller, I:Absorption chiller-heater
J:Air-cooled package air conditioner (incl. VRF), K:Water-cooled package air conditioner (incl. VRF)
L:Gas engine-driven heat pump, M:Water heat storage unit, N:Ice storage unit, DHC:District heating and cooling

Each categorized type can be described as follows. Monthly energy consumption distributions are shown in Figure 5. Bold lines indicate averages for the categorized types.

Type I (low): Energy consumption is relatively low (1,317MJ/m², 366kWh/m²) and the difference of monthly energy consumption is around 50MJ/m2. Since the internal heat generation is relatively low, there is more energy consumption in the heating season.

Type II (medium): Energy consumption is about average (1,679MJ/m², 466kWh/m²) and the difference of monthly energy consumption is around 60MJ/m².

Type III (high) :Energy consumption is high (2,519MJ/m², 700kWh/m²) and the difference of monthly energy consumption is nearly 70MJ/m². Since the internal heat generation is

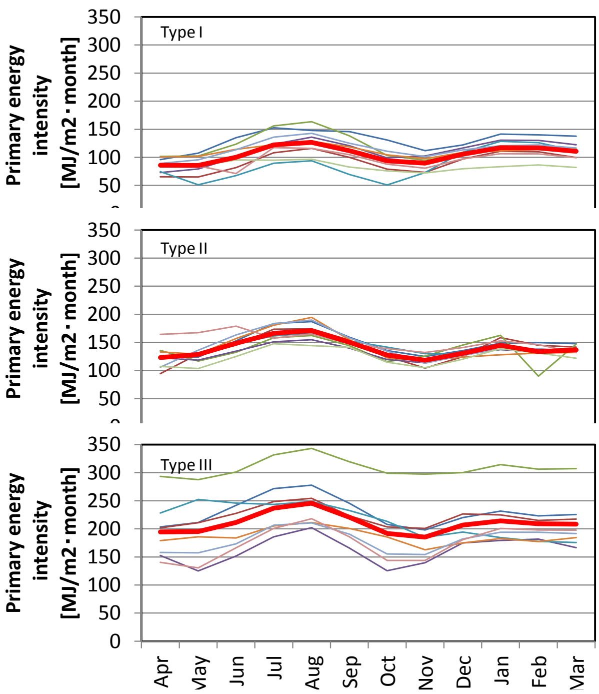

Figure 5 Categorized monthly energy consumption

high, energy consumption in the summer season is very high.

Considering usage of an energy consumption model, it is very useful that the model provides the primary energy consumption pattern if the user decides the type of heat source equipment. But as shown in Table 4, most of the buildings in this study installed multiple types of heat source equipment. It therefore isn't easy to model the specific relation between the energy consumption pattern and the heat source equipment. In this study, it was decided not to take into account the difference of heat source equipment in the model, except for the thermal storage unit. Regarding the energy consumption pattern of representative days, the existence and operation of thermal storage unit makes a big difference. For this reason, each type was divided into two categories depending on the existence of a thermal storage unit. As a result, a total of six energy consumption patterns were developed.

From the DECC detailed database, hourly energy consumption for representative weekdays, Saturdays and Sunday/holidays was calculated for each building using the following formula..

$$E_{av.(w,m,h)} = \frac{\sum E_{(w,m,h,n)}}{n_{(w,m,h)}}$$

w :weekday, Saturday or Sunday/holiday

$E_{av.(w,m,h)}$:Averaged energy consumption at h hours on w days in month m

$E_{(w,m,h,n)}$:Energy consumption value at h hours on the day in month m

$n_{(w,m,h)}$:Number of buildings at h hours on w days in month m

Average values $E_{av.(w,m,h)}$ were calculated for models 1 to 6. Figure 6 shows the result. On Saturday, only a few buildings operated in FY2011 because of energy-saving behavior, so the energy consumption pattern is similar to that on Sundays/holidays. Buildings that have thermal storage units (dotted lines) consume energy in the night to store the heat, which is the main difference from those without thermal storage units (solid lines).

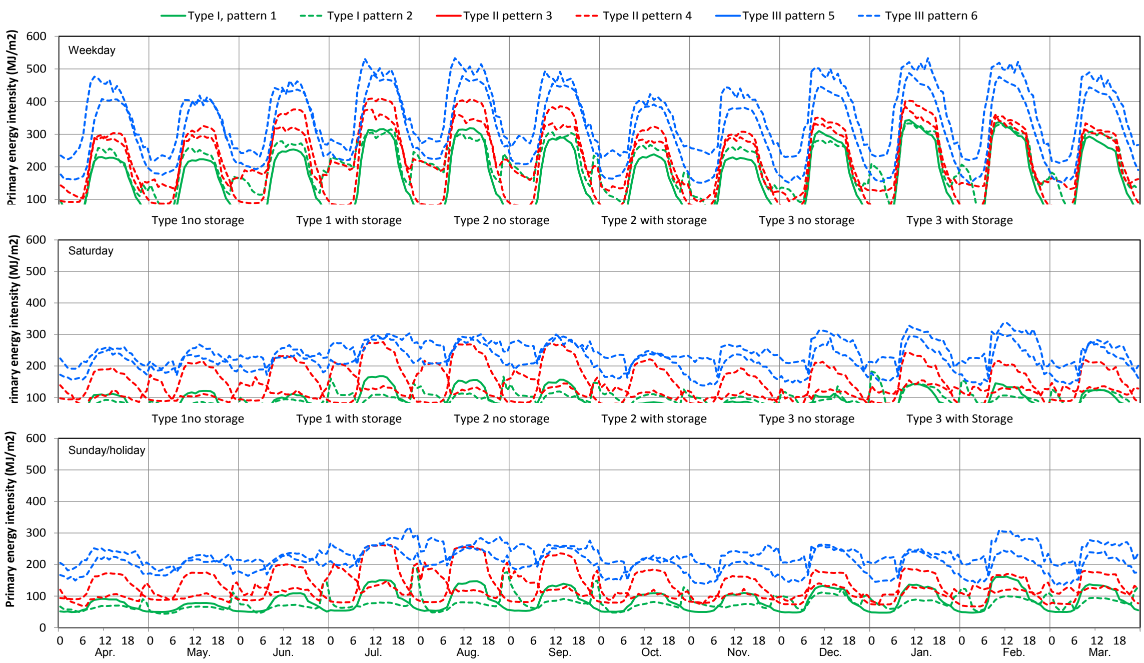

Figure 6 Averaged hourly energy consumption for representative days

Next, each datum shown in Figure 6 was normalized with the average value for each type shown in Table 4. For example, patterns 3 and 4 were normalized with the average value for Type II, 1,679MJ/m^2 (466kWh/m^2). As a result, the developed models are expressed as a ratio to the annual primary energy intensity, as shown in Table 5. Table 6 outlines each model. If the user assumes and inputs the annual primary energy intensity of the building the model provides energy consumption profile of the representative day of the month.

Table 5 Image of developed model

Month	Time	Weekday						Saturday						Sunda/Holiday					
		model1	model2	model3	model4	model5	model6	model1	model2	model3	model4	model5	model6	model1	model2	model3	model4	model5	model6
Apr.	0–1	0.041	0.072	0.057	0.085	0.064	0.090	0.042	0.055	0.058	0.083	0.068	0.089	0.039	0.051	0.056	0.072	0.066	0.081
	1–2	0.039	0.052	0.056	0.080	0.065	0.089	0.040	0.046	0.057	0.075	0.066	0.083	0.038	0.044	0.055	0.060	0.065	0.078
	2–3	0.038	0.043	0.055	0.073	0.064	0.091	0.039	0.043	0.056	0.067	0.065	0.077	0.039	0.044	0.054	0.053	0.061	0.072
	3–4	0.038	0.039	0.055	0.070	0.064	0.098	0.039	0.042	0.056	0.065	0.062	0.076	0.037	0.043	0.054	0.049	0.064	0.073
	4–5	0.038	0.039	0.055	0.066	0.066	0.103	0.039	0.042	0.056	0.053	0.063	0.076	0.038	0.040	0.054	0.046	0.059	0.076
	5–6	0.039	0.038	0.055	0.063	0.068	0.118	0.040	0.042	0.056	0.049	0.064	0.078	0.039	0.038	0.054	0.043	0.063	0.078
	6–7	0.048	0.047	0.066	0.062	0.080	0.155	0.044	0.045	0.061	0.047	0.062	0.085	0.043	0.039	0.057	0.041	0.064	0.085
	7–8	0.091	0.085	0.098	0.074	0.108	0.182	0.047	0.049	0.071	0.045	0.067	0.084	0.045	0.044	0.064	0.041	0.066	0.085
	8–9	0.134	0.135	0.134	0.140	0.137	0.189	0.071	0.054	0.090	0.059	0.080	0.092	0.060	0.045	0.082	0.053	0.074	0.094
	9–10	0.165	0.168	0.170	0.172	0.150	0.187	0.082	0.059	0.108	0.058	0.088	0.095	0.066	0.047	0.097	0.054	0.081	0.100
	10–11	0.174	0.196	0.176	0.168	0.162	0.181	0.082	0.063	0.112	0.063	0.095	0.101	0.068	0.050	0.097	0.058	0.089	0.098
	11–12	0.175	0.194	0.177	0.173	0.160	0.180	0.083	0.067	0.112	0.065	0.097	0.101	0.069	0.052	0.100	0.057	0.086	0.100
	12–13	0.171	0.185	0.172	0.168	0.160	0.185	0.081	0.070	0.113	0.062	0.098	0.102	0.069	0.052	0.102	0.058	0.090	0.096
	13–14	0.173	0.194	0.177	0.169	0.161	0.170	0.084	0.070	0.113	0.064	0.100	0.103	0.068	0.052	0.103	0.061	0.086	0.098
	14–15	0.173	0.190	0.181	0.171	0.161	0.178	0.085	0.069	0.116	0.074	0.094	0.100	0.068	0.053	0.102	0.063	0.089	0.096
	15–16	0.170	0.174	0.181	0.166	0.158	0.170	0.082	0.064	0.108	0.072	0.096	0.102	0.068	0.053	0.102	0.063	0.089	0.096
	16–17	0.165	0.162	0.180	0.163	0.154	0.160	0.079	0.065	0.106	0.063	0.094	0.101	0.063	0.053	0.101	0.061	0.086	0.095
	17–18	0.160	0.155	0.172	0.156	0.145	0.146	0.077	0.064	0.104	0.061	0.090	0.103	0.061	0.052	0.099	0.058	0.085	0.095
	18–19	0.129	0.135	0.144	0.135	0.130	0.138	0.061	0.062	0.096	0.061	0.087	0.097	0.052	0.049	0.088	0.056	0.083	0.093
	19–20	0.107	0.111	0.123	0.102	0.114	0.119	0.056	0.057	0.090	0.056	0.086	0.095	0.049	0.046	0.081	0.054	0.079	0.094
	20–21	0.082	0.094	0.107	0.088	0.104	0.119	0.053	0.052	0.084	0.054	0.081	0.088	0.047	0.044	0.076	0.051	0.078	0.096
	21–22	0.069	0.084	0.092	0.076	0.089	0.103	0.049	0.048	0.076	0.051	0.076	0.084	0.045	0.045	0.070	0.050	0.076	0.089
	22–23	0.054	0.110	0.073	0.093	0.079	0.104	0.043	0.058	0.065	0.067	0.073	0.081	0.041	0.069	0.061	0.075	0.068	0.079
	23–0	0.045	0.095	0.062	0.090	0.075	0.088	0.021	0.046	0.058	0.072	0.069	0.079	0.039	0.060	0.057	0.084	0.068	0.082
May	0–1	0.041	0.109	0.054	0.094	0.072	0.087	0.043	0.067	0.055	0.103	0.080	0.085	0.039	0.038	0.054	0.075	0.068	0.079
	1–2	0.040	0.086	0.053	0.096	0.071	0.091	0.042	0.065	0.054	0.095	0.075	0.081	0.038	0.037	0.053	0.064	0.066	0.074
	2–3	0.039	0.069	0.052	0.082	0.069	0.094	0.041	0.063	0.053	0.092	0.074	0.078	0.038	0.035	0.052	0.062	0.066	0.071
	3–4	0.039	0.060	0.052	0.088	0.072	0.092	0.040	0.057	0.053	0.089	0.074	0.076	0.038	0.033	0.052	0.059	0.066	0.073
	4–5	0.039	0.052	0.052	0.084	0.073	0.089	0.041	0.055	0.053	0.072	0.071	0.079	0.038	0.034	0.052	0.057	0.066	0.075
	5–6	0.039	0.050	0.053	0.083	0.076	0.099	0.041	0.055	0.054	0.063	0.072	0.085	0.039	0.034	0.053	0.053	0.067	0.076
	6–7	0.044	0.055	0.062	0.080	0.080	0.115	0.043	0.055	0.058	0.054	0.076	0.085	0.041	0.036	0.056	0.053	0.072	0.078
	7–8	0.063	0.096	0.094	0.086	0.100	0.151	0.049	0.047	0.072	0.054	0.077	0.067	0.044	0.038	0.065	0.053	0.075	0.070
	8–9	0.108	0.163	0.129	0.136	0.128	0.161	0.064	0.050	0.095	0.063	0.080	0.085	0.050	0.045	0.082	0.055	0.076	0.078
	9–10	0.151	0.185	0.170	0.166	0.147	0.161	0.080	0.056	0.116	0.060	0.091	0.092	0.056	0.047	0.096	0.055	0.082	0.083
	10–11	0.164	0.195	0.181	0.167	0.158	0.160	0.086	0.060	0.125	0.062	0.098	0.093	0.058	0.049	0.102	0.057	0.087	0.084
	11–12	0.167	0.194	0.185	0.177	0.158	0.153	0.088	0.061	0.124	0.062	0.102	0.094	0.058	0.051	0.104	0.059	0.088	0.085
	12–13	0.166	0.184	0.182	0.170	0.160	0.166	0.086	0.063	0.124	0.062	0.102	0.091	0.059	0.050	0.104	0.061	0.091	0.086
	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Table 6 Summary of developed model

Model	Energy consumption	Typical primary energy intensity	Thermal storage unit	description
1	Small	1,300MJ/m^2 (361kWh/m^2)	No	Relatively small buildings, heat load is small.
2			Yes	
3	Medium	1,700MJ/m^2 (472kWh/m^2)	No	Average buildings, heat load is medium.
4			Yes	
5	Large	2,500MJ/m^2 (694MJ/m^2)	No	Large scale buildings, heat load is large.
6			Yes	

In the process of designing or planning DHC plants or area-wide energy sharing systems, if the annual primary energy intensity is estimated and its energy consumption type (low, medium or high) is decided, the model automatically provides hourly energy consumption of a representative day for each month. In designing DHC plants or area-wide energy-sharing networks, it is very useful to determine the appropriate capacity of heat source equipment and to optimize the network. Energy consumption models for other building uses will be developed in the same manner as described in this paper. Use of these models could be expected to assist achievement of the optimal design for DHC or building energy systems.

5. Conclusions and future activities

This paper presented an overview of the DECC basic database and how it has been used by users since its release on the web. The DECC has been downloaded about 2,500 times by various users such as facility engineers, researchers and building designers. They typically use it as a reference when they plan or design energy-saving measures.

As an example of utilization of the DECC detailed database, the paper then described the development of standardized hourly energy consumption model for office buildings. The model consists of three energy consumption types (high, medium, low), and each type is subdivided based on whether or not the building has a thermal storage unit. Use of these models assists optimal design of DHC plants or building energy sharing networks.

It is necessary for the DECC Committee to increase number of data especially for the detailed database. Moreover, data ought to be collected periodically to obtain trends of energy consumption, although this is not easy to do continuously. One possible solution is use of the web. For example, if users input their building energy data on the web, the data can be automatically added to the DECC database. In return, users could receive the results of some kind of evaluation of their building energy efficiency as compared to that of other buildings.

The DECC detailed database will be released on the web soon, and it is expected to be utilized for more diverse purposes. The authors intend to develop a standardized hourly end-use load profile model for each building use as the next step.

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The secrets of load profiles

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Abstract: For years the electricity grid operators records the load profile every 15 minutes of customers, whose electricity consumption is over higher than 100,000 kWh/a or a power consumption higher than 50 kW (costumers with special contracts). These time series illustrate very well how the object´s demand structure looks like. By applying a standardized analysis tool based on MS Excel the load profile is evaluated economically and energy saving potential > 10% is reached. Usually it is not necessary to inspect the property directly. About 300 analyses have helped to create an extensive knowledge of electricity demand structures mainly in services buildings.

Keywords: Load profile, energy analysis, benchmarks, standardization, analytical tool, electricity

1 Starting Position

Whereas several significant achievements have been made in energy saving and efficiency of space heating during the last years, less improvement exist for electricity demand. Since the year 2000, in Austria the electricity demand has grown by 22.3%. Commercial buildings, especially hospitals are affected by this increase much stronger: During the last four to five years many hospitals have experienced an annual increase of three to four percent. In most cases neither the structure of usage nor the reasons for the increase are known.

Table 1: Tabular representation of a time series (Example secondary school in Salzburg)

TIme	Power
Date & time	[kW]
06.11.2012 05:15	3.2
06.11.2012 05:30	4.8
06.11.2012 05:45	4
06.11.2012 06:00	4.8
06.11.2012 06:15	5.6
06.11.2012 06:30	11.2
06.11.2012 06:45	14.4
06.11.2012 07:00	11.2
06.11.2012 07:15	12.8
06.11.2012 07:30	10.4
06.11.2012 07:45	15.2
06.11.2012 08:00	13.6
06.11.2012 08:15	11.2
06.11.2012 08:30	12

How to analyses quickly a service building with an annual electricity consumption of less than 500.000 kWh/a to provide an economic evaluation of its demand structure and thus its potential for saving energy without investing a lot of effort, is a question that arises rapidly. Qualitative and valuable conclusions can be drawn from energy monitoring systems. Depending on the duration of measurement, excellent data can be provided. To offer these kinds of data not only (reasonable) investments are required but also time is needed - from the moment of authorization for the investment until the data is available.

To conduct a qualitative analysis quickly, data of the overall consumption (data from the main electric meter of the utility) is sufficient if the user consumes less than 500 MWh. For years grid operators have recorded the electricity demand of costumers with energy consumptions higher than 100.000 kWh/a or the maximum power levels of over 50 kW. The average power consumption is determined every 15 minutes and recorded (data structure see table 1). On the day prior to the implementation of smart meters, most costumers and even energy consultants are not aware of the fact that records of the time data series on energy consumption already exist and that individual measuring is not always necessary.

For short termed applications consumption curves depicting the object´s overall demand in form of cardioids are available. Figure 1 shows the consumption curve of school during a period of 17 days.

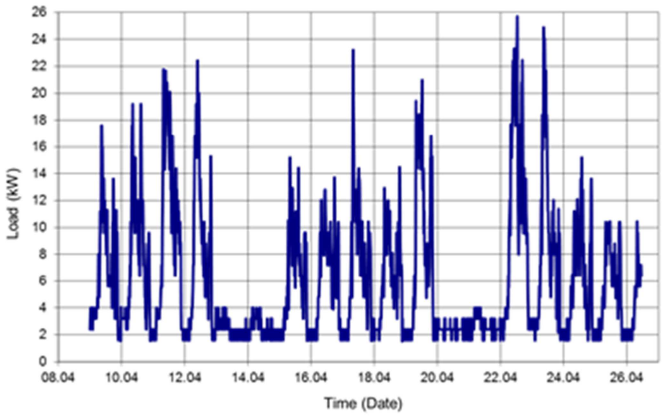

Figure 1: Graphic representation of a load profile (17 days in secondary school in Salzburg, Austria)

If requested electricity grid operators in Austria and also in many other EU Member States have to supply their clients with this data - at least once a year without charging a fee. Some electric utilities provide on line services where these data series are available given for small fees (ca.€ 7/month) daily. Mostly the dates are covering the time until the previous day. Normally the data is made available in Excel files.

35,000 individual records with time information are provided when ordered for the last twelve months. These records show how an object “behaves”. As a first step, this data can be combined with the outside temperature (average daytime temperature). In this way, comprehensive data for analysing are available. Recommendations for increasing energy efficiency can be derived through analysing. Experience from conducting 300 analyses has shown that these time series do not only result in excellent analyses for objects with a consumption lower than 500 MWh, but are also applicable for objects with higher consumption levels. The evaluation of a hospital with a consumption of over 11 GWh could demonstrate the management that there is the need for further monitoring the energy consumption.

2 Load Profile Analysis

e7 has developed a tool based on MS Excel for analysing load profiles in a standardized way. Thanks to the information provided in form of around 35 different figures and additional benchmarks, the consumption curve can be interpreted within short time. Which information provided by the graphic representations and individual records is used for interpretation, depends within the expertise of the observer. Of course the standardisation of data is very helpful, since it enables the expert to interpret all curves in an uniform way.

Even though the object´s inspection is not necessary, the conversation with the object´s operator of topics related to the analysis is crucial. Firstly, he or she knows the usage structure of the object better. Secondly, it shows whether the client´s expectations differ from the object operators´.

Thanks to the visual representation it will be easier to explain the situation to the object operator. Experiences made so far, have shown that this transparency evokes a high disposition to implement energy efficiency measures.

3 Evaluation

Excel is the most suitable tool for evaluating, since it is easy to handle and positive experiences have been made. The modification of additional enquiries is easier than using a separate web based tool.

The tool´s entire assets become visible after using it several times, since abnormalities are detected easier. By analysing and comparing several evaluations (standardisation) it easier to see if individual load profiles met the expectations and if some require more detailed monitoring.

A project to provide a web based solution has already been initiated.

3.1 Benchmarks

Following benchmarks are currently applied:

1. Specific consumption per reference parameter (m^2, beds, co-workers, ...). Four different reference parameters may freely be chosen, e.g. kWh/ m^2 a.
2. Specific base load: Specifies the power consumption (e.g. W/m^2) during night or on weekends. Food discount retailers no matter of which chain usually always show almost the same parameters (21 Watt/m^2). Offices usually have a specific base load of 6 Watt/m^2.
3. Base load consumption: Specifies how much of the annual electricity consumption is caused by the base load. This should not to be underestimated. In many discount shops this consumption has a share of approximately 52%, hospitals up to 78%.
4. Consumption of 4000 hours: Here the assumption is made that a commercial building (e.g. office) operated 4,000 hours a year. The percentage indicates the consumption which exceeds annual electricity consumption outside these 4,000 hours. Experiences have shown that offices surpass this by 30%. This means that 30% of an office´s electricity consumption occurs when nobody uses the building.
5. Peak load percentage: How high is the share of the peak load caused by the 25 hours with the highest power. This value indicates if there is a possibility the reduce the peak load and give information about the structure of the peak power is.

3.2 Figures

Around 35 different graphic representations help conducting a well-grounded analysis of the consumption within one to two days. Among other things following visualizations are used:

1. Arranged load profile: The power values are displayed in a 15 minute tact and in descending order by its size. This figure illustrates very well, how much energy the object is consuming outside the times where it is mainly used (Figure 2). To some extent conclusions regarding the use of the building can be drawn by interpreting the curves´ forms.

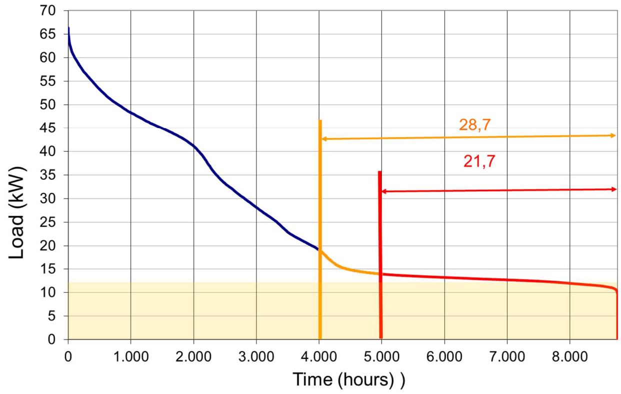

Figure 2: An administration building´s permanent base load. The area on the right side of the orange line displays the consumption (28.7%) made outside the operation hours (4.000 h) of the building.

Comparison between two seasonal load profiles depicting certain week days (

2. Figure 3 3).
    a. If the average of the same weekdays is applied three weeks in a row, the individual events are diluted and seasonal events are displayed in a clearer way. Thus, seasonal impacts such as heating, cooling and illumination, become more visible. For instance this approach helps displaying elevated consumption levels during night time caused by cooling or heating devices.

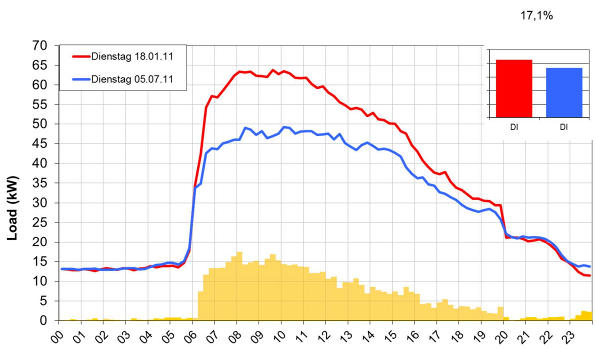

Figure 3: Comparison of two load profiles of an administration building during the day: Tuesday in January (January 18th) and July (July 5th). The consumption differs by 17.1% probably due to the illumination. The curves don´t depict any deviation during the night (circular pump????) but during the day it differs by almost 15 kW (illumination). The building starts operating at 05:45 AM. The maximum demand for electricity occurs from 08:00 AM to 12:00 AM.

3. Load profiles during holidays (no images). This figures shows how a building „behaves“, when e.g. an office building is not used during holidays and there is no demand for energy. Experiences have shown that, despite this, building services are kept running. With this insight, operation hours of individual subsections might be determined.

4. Visualization of the weekly consumption´s average consumption and its procentual deviation (Figure 4). This graphic representation depicts seasonal dependencies in form of tangible magnitudes.

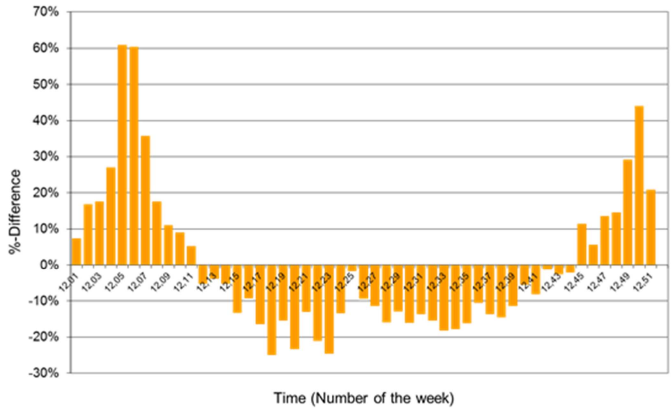

Figure 4: Percentage deviation from a car dealer´s consumption during certain weeks and her or his average consumption. This chart illustrates an additional demand, especially in winter (additional electrical heating device??)

5. Consumption during night time (f.e 10:00 PM to 04:00 AM)

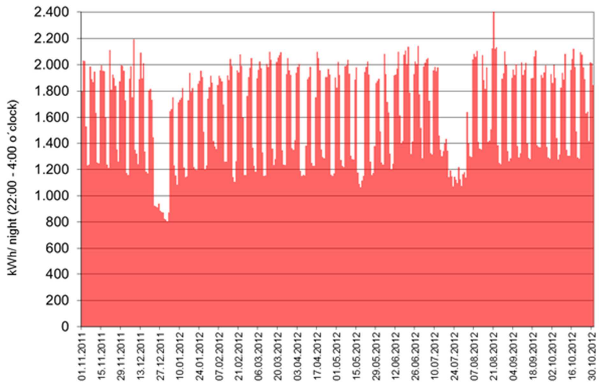

Figure 5: Electricity consumption of a production plant during nigh time (10:00 PM to 04:00 AM). It is clearly evident that the plant was not operating during Christmas and in summer, even though there is a consumption of over 800 kWh during the night. A slight increase of power is noted during the period of observation. The fact that the electricity consumption at night time during the weekends is lower, is not typical: As soon as the plant was informed that it consumes approx. 150 kW even on days where it is closed, comprehensive measures were taken. The main reason was the clean room, since it was operating fully even on holidays. By setting numerous small measures (particularly regarding the ventilation system´s regulation) 11.2% electricity is saved. The extent of additionally saved heat is unknown.

6. Comparison of individual days of a calendar week (without images). This illustrate whether individual weekdays possess a similar load profile and if every day has an individual demand structure.

7. Daily consumption and its connection to the average temperature during daytime. This figure depicts the daily consumption and its connection to the daily average temperature. In particular cases it may be necessary to ignore holidays and weekends among other things in the visualization.

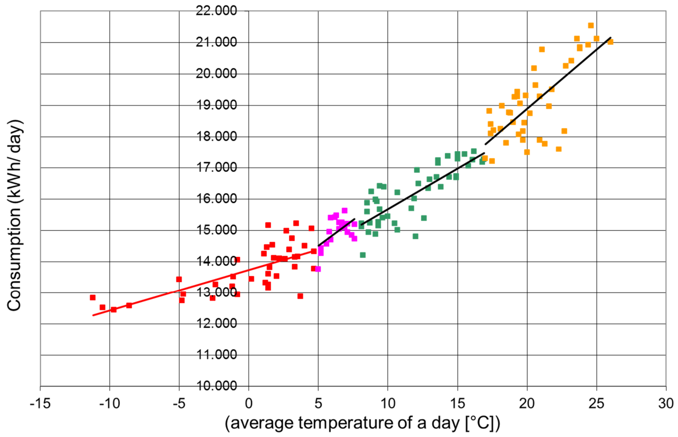

Figure 6: A wholesaler´s (comestibles) daily consumption and its connection to the average temperature during day time (°C). The graphic demonstrates that the electricity consumption depends on the outdoor temperature. It is assumed that the object was cooled by an air source heat pump.

8. Power consumption of certain weekdays at specific times (no images): This figure reveals if the power consumption (at e.g. 02:00 AM) of a specific period changes and if there is a specific date when power consumption has obviously grown.
9. The interconnection of the consumption of single weekdays (no images)
   a. This visualization illustrates if an object shows an elevated consumption during certain week days. This way, a nursing home´s washing day home as well as other things were detected. Even in offices such differences are detected, these deviations do not include Fridays where people usually leave work earlier.
10. Comparison of permanent base load curve depicting a short period (e.g. three weeks).

4 Previous Experiences with the Tool

Up to now, approx. 300 load profiles were analysed. The same approach was applied for every single analysis, extending the evaluation options multiple times due to the new insights the experiences brought new awareness with them. For example in the mean time the number of working days in an office building, in a school can be determined in a simple way.

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Following kinds of properties were already analysed:

Kinder gardens
Primary schools
Secondary schools
Vocational schools
Government agencies and offices
Nursing homes
Hospitals
Soccer stadia
Ice hockey stadia
Ski lifts

Comestibles - retail
Comestibles - wholesale
Hardware stores
Clothing markets
Hotels
Different kinds of trades in manufacturing
Butchery, gravel mill, car dealer, lumber mill
Gas stations

Counselling experience

The tools´ advantage is rather the improved graphic processing of the demand situation than the determination of the savings potential. The graphic visualization helps the user of the object to determine if the actual load profile meets her or his expectations. Usually an exact description of the situation is sufficient to stimulate measures. For instance pointing out the time of changes in the demand structure may be sufficient to initiate further proceedings.

4.1 Duration of analyse

Approx. 1.5 days are required for conducting a standardized analysis and producing a report encompassing 20 to 25 pages.

4.2 Savings Potential

Our experience has shown that a standardized analysis of the load profile causes a potential for saving energy of 10% without expecting the property directly. Do get a better understanding of the situation within the single building, sometimes we use web conferences to discuss the situation with the use.

Our experience has shown that the analysis is only an intermediate step towards final results. For instance, a consultant detected an energy saving potential of 8%, but the analytical report offered even more information for the property owner. This helped the object operator to implement measures saving 18% of the energy consumed.

To which extent these experiences of energy saving potentials are applicable to private households (smart meters) cannot be established.

4.3 Target Group

The analysis of load profiles is especially suitable for objects consuming less than 500 MWh. A comestible discount store consumes 250,000 kWh - an example to grasp the proportionality of these dimensions. Thus, a market segment difficult to counsel in questions of energy efficiency due to economic reasons is now much easier, especially for small consumers.

Even though the analysis was designed for small consumers, it is also applied to bigger consumers, e.g. 20 hospitals were analysed on their request (consumption up to 11 GWh). This mainly helped to create a sensibility for measures affecting the base load, but also successful energy saving measures have been proven several times.

4.4 Base Load

Generally the base load is very high. Here great potential for energy saving exists. In table 2 following ways of using an object and their corresponding basic consumption caused by the base load are presented:

Table 2 Common share of annual electricity consumption caused by the base load.

Use of the object	Percentage of the base	Comments

	load within the overall consumption	
Hospitals	62-78%	Elevated value (78%) even though it is not an acute hospital!
Comestibles discount shop	52%	Same benchmark observed in different store chains
Governance agencies	48-70%	Elevated values due to cooling of IT-systems
Primary schools	25%	including holidays
Nursing homes	52-57%	
Hotels	62%	
Clothing markets	7%	Peak value (ignoring the cooling- and ventilation systems, since it comes from a central facility)

4.5 Composition of the demand structure

In some cases the demand structure and its part may be assigned to individual users by using the load profile. This requires even more experience. Currently, a research project is investigating top down (load profile) and bottom up approaches for the same 25 objects to improve the analysis method.

- Illumination: In the case of a comestible discount store not only the illumination´s power of connection was determined (23 W/m^2), but also the annual consumption. Whereas energy consultants receive 25% according to calculations of the actual load profile, there are still values up to 35% saved
- Cooling: Hospital with cooling requirements caused by outdoor temperatures form 7% of the entire annual consumption.
- Reasons for elevated base loads in the business sector are u.a. cash machines and anti-burglary protection devices.
- An underestimated problem might be electric water heating. This is partly due to the elevated requirements enforced by the drinking water ordinance (legionella).

5 Thermal analysis

In the meantime, several thermal load profiles were analysed, too. This was more demanding, since it was difficult to use the experience from the electricity load curves analyse. Therefore an individual analysis method was required differing strongly from the method used for electricity analysis.

We didn´t only manage to illustrate whether the control for the heater is set correctly, but also the percentage of warm water used for the heating and warm water. In the case of a hospital we demonstrated that 45% of the specific heat consumption (138 kWh/m^{2}a) is used for warm water and/or circulation of warm water

Generating electricity demand-side load profiles of the tertiary sector for selected European countries

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ABSTRACT

Energy efficiency is regarded as one of the most important measures to secure a reliable, environmentally compatible and economical energy supply. Hence, better understanding of electricity consumption is required. This includes both disaggregations regarding subsectors and energy services and regarding temporal resolution. Insights into hourly electricity consumption patterns (i.e. load profiles) enable us to understand the impact of energy efficiency measures on the supply side and to make flexibilisation potentials available for demand side management.

Three methodical streamlines are introduced to generate and assess hourly load profiles of the tertiary sector for selected European countries. These approaches are based on norms and standards, load information from building simulations, and on measured electricity consumption data combined with questionnaire surveys conducted in the measured object.

The first methodical streamline uses information of building norms and standards that include generic profiles for building occupancy by building type and room type. Based on this information generic hourly load profiles for building related energy services such as lighting and ventilation on the one hand side and for person related profiles such as ICT use in offices and hot water use in hotels on the other hand side are generated for a given country. Referring to cultural differences and habits such as lunch break times and opening hours adjustments are made for defined country groups. Through an allocation of room types to building types and of building types to economic sub-sectors an aggregated load is generated by sub-sector and by country-group. Using regression techniques the second method relates building simulation results to explanatory variables such as temperature and radiation to estimate the weather dependency of loads of energy services such as heating, cooling, and lighting. Thirdly measured electricity consumption data and questionnaire surveys are used to define the global electricity profiles of about two hundred and ninety companies of the tertiary sector. Using regression analysis these global electricity consumption profiles are related to explanatory variables such as building equipment and use profiles. Empirical profiles are also used to validate generic profiles generated by the first and second method.

Finally, linking obtained load profiles with detailed bottom-up models allow forecasting the aggregate load curves of the tertiary sector.

INTRODUCTION

Energy efficiency is regarded as one of the most important measures to secure a reliable, environmentally compatible and economical energy supply. Hence, better understanding of electricity consumption is required. This includes both disaggregations regarding sub-sectors and energy services and regarding temporal resolution. Insights into hourly electricity consumption patterns (i.e. load profiles) enable us to understand the impact that structural changes on the demand side and energy efficiency measures may have on the supply side which is of highest relevance for the power sector (1). Moreover from well-known load profiles on a disaggregated level flexibilisation potentials that may be tapped by demand side management may be derived.

Load profiles represent a time-discrete[1] characteristic distribution of electricity consumption over a specific period of time. Load profiles exist for single consumers (describing the consumer specific consumption pattern) or as a mean load distribution of a group of similar consumers, which are usually referred to as standard load profiles[2]. The latter are used by utilities for hourly load prediction

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[1] Load profiles are most commonly available on an hourly basis, but they can also be disaggregated on a quarter-hourly or even more precise time scale.

[2] Since standard load profiles are supposed to describe an average load pattern, their representativeness increases with the number of (similar) consumers whose load behavior shall be represented.

to estimate the expected consumption of consumers without continuous, hourly demand metering[3] (2), (3). Consumers without registering consumption metering comprise households, small commercial businesses and agricultural holdings[45]. By multiplying the consumer's standard load profile with the demand forecast of the upcoming year (which is based on the metered consumption of the previous year), the utility is provided with the future demand load curve. Apart from the short to mid-term load forecast, load profiles play an increasingly significant role in the context of long-term energy system modelling and generation as well as infrastructure capacity planning. In (4) load profiles are used to estimate the evolution of the overall system load curve and the related impacts on the electricity supply side. In this context it becomes obvious that appliance and technology specific load profiles are required in order to properly represent the technological changes (e.g. penetration of new technologies, phase-out of traditional appliances) that are going to occur within the upcoming decades (according to the results from bottom-up demand forecasts such as (5) and effecting the system load curve.

Hence, the present article deals with the bottom-up generation of aggregated electricity demand load curves of the tertiary sector which are based on highly disaggregated sub-sector, energy service and technology specific load profiles. After a short overview of currently existing methodologies (state of research) we explain in the method three approaches for the generation of load profiles for the tertiary sector based on norms and standards, results from building simulation models as well as from field surveys. We conclude with the presentation and interpretation of some exemplary results and some final remarks.

State of research

There are different methodologies for generating hourly load profiles. Their applicability mainly depends on the question whether the aggregation level of the profiles required exceeds the level of detail of the input data being available or not. In the first case load measurements need to be disaggregated or artificially generated by simulation models whereas in the second case data simply needs to be representatively clustered and averaged and eventually aggregated.

Beginning with the simpler option, there are a number of reports describing how to determine load profiles using data of the same granularity. The most common approach consists of the segmentation of hourly (or even more detailed) load measurements by grouping companies into representative sub-sectors using fuzzy c-means clustering. This approach is for instance applied by (6) when generating the first set of standard load profiles for Germany. 617 commercial load measurements recorded in the mid 1980s were clustered into synthetic load profiles of seven sub-sector specific groups[6]. (7) carries out a similar approach based on load records from the years 2004/2005 in 1549 German companies, distinguishing among ten commercial sub-sectors. In both studies load profiles are generated for nine typical days[7] by averaging all load measurements belonging to the same cluster. In (8) 226 year-long load measurements in the UK included sub-sector specific and energy service specific data. Hence, calculated sub-sector load profiles can be further decomposed into energy service specific load profiles.

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[3] In Germany this concerns all consumers featuring an annual electricity consumption of less than 100,000 kWh. All consumers exceeding this threshold are metered on a quarter-hourly basis.

[4] §12 of (34) defines for which consumer groups standard load profiles need to be used: business, households, agricultural holdings, base load consumers, interruptible loads and heating storage devices.

[5] German standard load profiles, distinguished by different types of commercial and agricultural businesses, were originally generated by (6). Subsequently, utilities adopted these profiles according to the specific characteristics of their individual consumer groups (see for instance (33)).

[6] These groups were distinguished according to opening hours or type of business (G1: weekday 8am-6pm, G2: main consumption in evening hours, G3: non-stop business, G4: shop/hairdresser, G5: bakery, G6: weekend business, G0: general business)

[7] Typical days are a combination of the day of the week (weekday, Saturday, Sunday) and the season (summer: 15.05. – 14.09., winter: 01.11.-20.03., transition time: remaining days) (6).

When it comes to the determination of highly disaggregated load profiles based on less detailed input data, different methods can be used. (9) gives an overview of approaches being applied on residential load measurements, which can be likewise used in the context of commercial load profile generation. All models are basically divided into top-down and bottom-up approaches, even though a strict distinction is not always possible and some models include elements of both types (hybrid models).

Top-down models, deterministic statistical disaggregation models, aim to decompose aggregated load measurements into more detailed load profiles, taking into account consumer specific information and macro data (such as number of persons per household, ambient temperature, appliance configuration). Conditional demand analysis (CDA) represents a form of regression analysis that tries to explain total load by a set of variables. Including the presence of specific appliances/technologies or energy services as variable allows deriving load profiles from the respective regression coefficients (see e.g. (10), (11) , (12) , (13)). (14) also classifies neural networks approaches in the group of top-down models due to similar input data (e.g. carried out in (15)).

Bottom-up models consider a variety of single consumers (i.e. household or business) and their characteristics which serve as a basis for the generation of an averaged representative load profile. Bottom-up models consist of three sub-groups according to (9). Statistical random models (e.g. (16)) simulate a large variety of synthetic appliance load profiles, taking into account occupation scenarios, appliance equipment rates, random appliance operation start time and per capita daily electricity consumption. Probabilistic empirical models (as applied in (17), (18)) use knowledge about total load, consumer habits and appliance specific parameters to determine individual appliance operation times of single consumers. Time of use based models take advantage of consumer diaries reporting highly disaggregated consumer behaviour as well as socio economic data and technical parameters to generate probability functions of activities implying the use of specific appliances (see e.g. (19), (20), (21)).

Statistical engineering models (such as the one developed in (22)) are labelled as hybrid models since they generate load profiles based on a bottom-up-approach, which are in a second step further adjusted using statistical coefficients.

The methods presented in the following represent advancements of the approaches mentioned above.

METHOD

Overview

A methodology to generate hourly load curves for the tertiary sector based on load profiles by subsector and energy service is developed in this article. The goal of the methodology is to model aggregated load curves by a bottom-up approach that is linked to existing bottom-up models that forecast annual electricity consumption. With such an approach it will become possible to model structural changes of future consumption and of energy-efficiency measures. By linking specific load profiles (by sub-sector and by energy service) to modelled annual energy consumption and to exogenous explanatory variables (such as weather, opening hours) it becomes possible to generate aggregated load curves for different countries and potentially for different scenarios.

The load curve generation process is structured into two parts (see **Figure 1** for a schematic overview). Part I consists of generating specific load profiles for different energy services, differentiated by sub-sector. Typically building physics simulation models, and norms and standards are used as a basis data source. For example, for heating and cooling demand of different building types hourly load data is used to derive a direct electric heating and cooling profiles respectively. Moreover norms and standards such as the Swiss SIA 2024 include information of the occupancy and appliance use profiles in different room and building types that can be used to derive occupancy related load curves, such as ICT use in offices.

After generating the load profiles by energy service, they are aggregated to create the global load curve of a certain tertiary sub-sector (Part II of the methodology). Aggregation is based on information about the energy consumption shares of the subsectors are based on annual consumption calculations carried out with the FORECAST model (5).

Ultimately validated load profiles will serve as an input to bottom-up load curve forecasting model called eLOAD (not part of this paper).

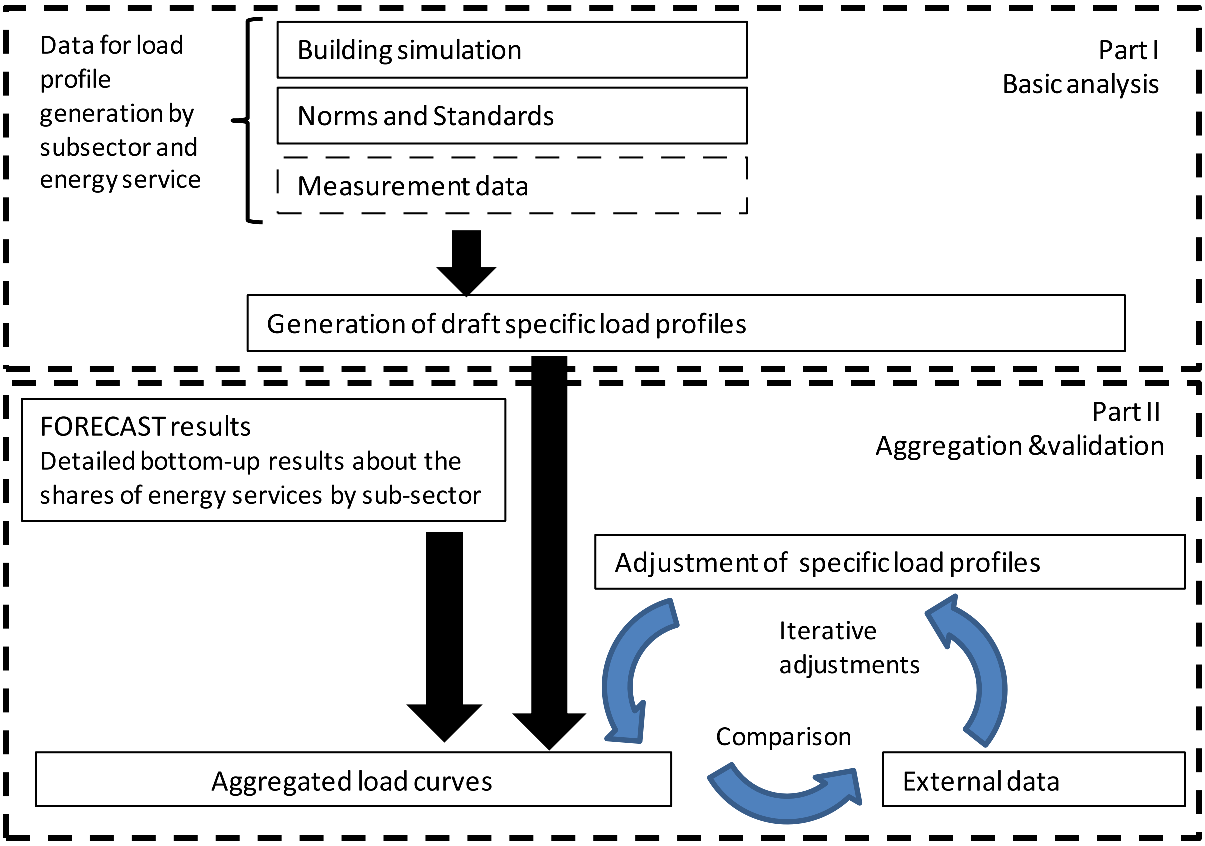

Figure 1: The schematic overview of the load curve generation process on the tertiary sector

Next the main methodological steps of the procedure are described in more detail:

Norms and standards

The first methodological streamline uses information of building norms and standards such as Swiss SIA 2024 (23), the Norm Calculation Method (NCM) database of the British Simplified Building Energy Model (SBEM) or the US ASHRAE standard 90.1 (24) that include generic profiles for building occupancy and appliance utilization by building and by room type. However actual energy consumption of various energy services differs from occupancy and appliances use, for instance for technical reasons (e.g. due to stand-by functionality). Hence, occupancy and appliance use profiles need to be “converted” to generic hourly load profiles for building related energy services such as lighting and ventilation as well as people related profiles such as ICT use in offices and hot water use in hotels are generated for a given country.

In the case of SIA 2014 generic occupancy and appliance use profiles are differentiated by room type. For instance, office buildings are differentiated by single office rooms, open office space, meeting rooms, corridors and staircases, technical rooms, and others. Similarly hospitals are composed of treatment rooms, bedrooms, corridors and staircases, technical rooms. Through an allocation of room types to building types and of building types to economic sub-sectors an aggregated load is generated by sub-sector and by country-group.

Yet generating load profiles based on norms and standards strongly depends on the available of such documents. Particularly norms and standards are available only for quite limited number of countries. Moreover underlying methodology of norms and standards may differ across countries which hinder comparability. Some of this limitation of data availability may be overcome by adjusting generic load profiles by taking into account cultural differences and habits such as lunch break times and opening hours, for instance differentiating by country groups.

Building simulation

Using regression techniques the second method relates results from building simulation models to explanatory variables such as temperature and radiation to estimate the weather dependency of loads of energy services such as heating, cooling, and lighting. Such results were generated in the context of previous research in (25), (26) and include hourly consumption data of heating, ventilation, cooling, lighting, appliances for various office building types (covering both existing and new buildings, low and high glazing shares, low and high internal load, low and high thermal mass respectively). In this paper the hourly heating demand results of the building simulation are used to generate the load profile of a direct electric heating in office buildings. Appling the estimated regression model and weather data of respective countries load profiles can be generated for different European countries.

The theory related configuration of the regression formula (i.e. identification of the explanatory variables) is based on principles of building physics that include also behavioral aspects of building use, on norms and standard that include schedules and occupancy profiles (as elaborated above), and on different analysis of case studies and field studies. Multinominal regression model approaches are then specified to testing the significance of different explanatory variables. For a given building type heating demand directly or indirectly depend on the outside temperature, solar radiation, internal heat loads, schedules of building occupancy, and set-points of building technology control (e.g. indoor temperature, ventilation and cooling, and lighting). These variables may depend on each other or may have an impact on other variables that influence heating demand. For example, internal heat loads depend on lighting control set-points and daylight availability and on the use of electrical appliances that dissipate heat to the rooms. Schedules of building occupancy impact on the need of ventilation and thus, indirectly on heating energy demand.

In order to be able to use regression results in the before mentioned model eLOAD season of a year, and type day (weekday, Saturday, Sunday) is also included in the regression model. The regression formula is defined as followed:

$$L = \alpha_1 + \beta_1 x_T + \beta_2 x_R + \beta_3 x_O + \beta_4 x_S + \beta_5 x_D + Interaction\ terms$$

in which

$$L = Load\ of\ \hbar our\ t$$

$$\alpha_1 = basis\ coefficient$$

$$\beta_i = regression\ coefficients$$

$$x_{T,R,O,S,D} = Outside\ temperature\ (T), radiation(R),\ \ occupancy\ (O),$$
$$season\ (S)\ and\ type\ day(D)\ at\ \hbar our\ t, respectively\ (S\ and\ D\ being\ binary\ variables)$$

The regression technique can also be used to derive load profiles of other energy services if the relevant information is included in the simulation results. If simulation results include hourly internal gains from lighting and appliances they can be used in the regression formula in order to establish load curves of these energy services. For instance, solar radiation, occupancy profile, and operation hours of the building are explanatory variables used in regression model for lighting.

Analysis of measured data and surveys

Measured electricity consumption data and questionnaire surveys are used to define the global electricity profiles of about 290 companies of the tertiary sector of the UK and about 280 small and medium enterprises (SME) of Ireland. In the case of Ireland these profiles are sorted for four different sub-sectors of the tertiary sector (27). Measured data are analyzed either by methods of descriptive analysis or by regression analysis. In the latter case global electricity consumption profiles are explained by explanatory variables obtained by questionnaire surveys and before mentioned type-days and season of the year.

Aggregation of generated load curves

After generating the load profiles by energy services and subsectors they are aggregated to describe the global load curve of the sub-sector. The aggregation is done by summing up the load curves weighted with their respective consumption share. These shares are based on annual electricity consumption data generated by the FORECAST model (5). Consumption data is distinguished by energy service, subsector, and country.

Validation

To improve the quality of the generated load curves they are validated and adjusted in an iterative process. Global load profiles by subsector are used to validate the generated load curves by energy services. The validation process consists of a comparison between the generated global load curves by subsector and external data and an adjustment of the specific load profiles in order to reduce deviations between modeled and measured load curves. If the deviation between generated aggregated load profile and external data is not satisfying pre-defined criteria, load curve adjustments are be performed. These two steps of comparison and adjustments may be iterated several times in order to reduce deviation between generated aggregated load profile and external data.

External data is based on other studies, measured electricity consumption data, and surveys. Depending on data availability comparison is made on the level of 24 hour load profiles of a limited number of type-days (e.g. weekday, Sunday and Saturday for three seasons of the year).

RESULTS

The FORECAST model calculates the current and future yearly energy consumption of 14 energy services[8] in the tertiary sector ((5), (28)). The SIA (Swiss Society of Engineers and Architects) norms and standards include profiles for occupancy and appliance distribution over time (29). The validation process is done by comparing the generated subsector specific global load curves to global load curves based on the external measured data in the Ofgem project described in (30). In that project less energy services[9] are taken into account than in the Forecast model. Using the yearly electricity consumption results of the FORECAST model, the most relevant energy services are selected and hourly load profiles are generated for the eight subsectors[10] of the tertiary sector and the nine type days[11] by the method described in this paper. The type days are used in order to reduce data in modeling. The following energy services are considered as the most relevant ones:

- Lighting
- Electric heating
- ICT office
- ICT data centers
- Ventilation
- Circulation pumps and other heating auxiliaries
- Misc. building technologies

In this section the selected results of the generated load curves by energy service and subsector are presented in the case of the UK. Finally, the aggregated load curve of the selected subsector is compared with the external data.

Norms and Standards

The occupancy and appliance distribution profiles of the norms and standards are used to guide the load curve generation of different energy services. As an example, the load profile of lighting can be

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[8] Lighting, Lighting street, ICT office, ICT data centers, Ventilation and air-conditioning, Circulation pumps and other heating auxiliaries, Electric heating, Heat pumps, Hot water, Elevators, Misc. building technologies, Cooking, Laundry, Refrigeration

[9] Catering, Computing, Cooling and ventilation, Heating, Hot water, lighting, and other (the rest of the possible appliances)

[10] Wholesale and retail trade; Hotels, cafes and restaurants; Traffic and data transmission, Finance, Health, Education, Public offices; Other services

[11] Summer Weekday, Saturday and Sunday; Winter Weekday, Saturday and Sunday; Transition Weekday, Saturday and Sunday

related to the general building occupancy profile given by building and room type used on the certain subsector, for example in Figure 2.

However, the lighting load profile does not follow the building occupancy profile directly. The studies in (31) show that the load without use is not zero as could be assumed. This means that stand-by losses of appliances and overnight lighting should be taken into account in the load profiles. The relation between the building occupancy and lighting profile is defined based on the experience of analyzing the building simulation results and on the country based behavioral assumptions of the subsector, such as operation hours. This is called as generation of a draft load profile in **Figure 1**.

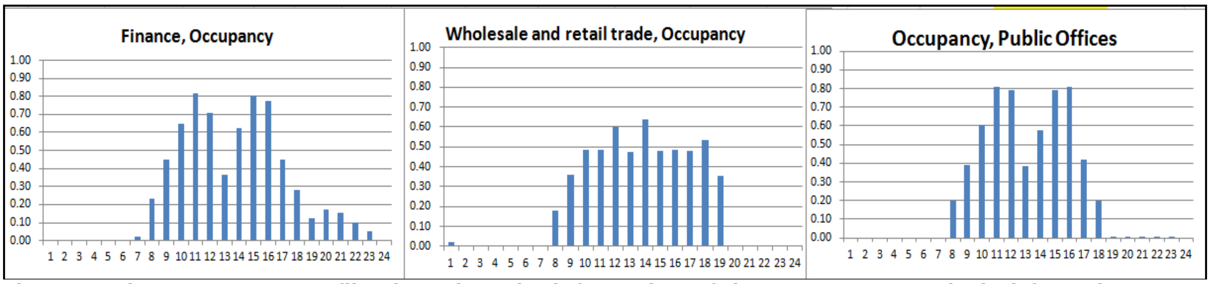

Figure 2: The occupancy profiles based on the information of the SIA 2024 norm in (23) for subsectors: Finance, Wholesale and retail trade, and Public offices.

As an example in Figure 2 the useful information to generate the lighting load profile on the finance subsector can be gained. There is the decrease in the occupancy at midday, which can be assumed to influence to the lighting profile as well. Additionally, there is a longer evening operation than on the Public offices subsector. By these two facts and taken into account the studies in (31) about the night load, the lighting load profile on the Finance sector can be generated. However, in this paper the building simulation results can be used to generate additional information regarding the lighting load profile in the offices.

The lighting profile in Figure 5 is based on the building occupancy profile. However, the night load and daylight saving are taken into account. During the unused time of the building the lighting load is not zero and during the weekdays electricity consumption is reduced due to regulating daylight sensors and reduced occupancy during the lunch break. The finance sector can be assumed to work also outside of the regular office working period because of the international co-operations, which leads to longer evening or morning operation depending on the co-operation country. However, only weekdays are assumed to be working days.

Building simulation

As an example of the method step **"Building simulation"** space heating with direct electric heating technology and lighting are selected as energy services. Three different office buildings types are simulated with IDA ICE building simulation program by using the local weather files from (32). The simulation program is a whole-year detailed and dynamic multi-zone simulation application for study of thermal indoor climate as well as the energy consumption of the entire building. (33) The main difference between the simulated buildings is in the glazing area of the façade because they present office buildings from the three different categories: new, medium and old offices.

The space heating demand results from the building simulation are used to find a regression formula for the direct electric heating. The regression formula is generally described in the method section. In this paper the following regression formula with the variables is used to generate the load curve for direct electric heating in the office buildings.

$$L = \alpha_1 + \beta_1 x_{T\_over15} + \beta_2 x_{T\_under15} + \beta_3 x_{idirnorm\_daybefore} + \beta_4 x_{idiffho\_daybefore} + \beta_5 x_{internalload\_daybefore}$$

in which

$$L = Load\ of\ hour\ t$$

$$\alpha_1 = basis\ coefficient$$

$$\beta_i = regression\ coefficients$$

$$x_{T_{over15}, T_{under15}, idirnorm_{daybefore}, idiffho_{daybefore}, internalload_{daybefore}} =$$

$$Outside\ temperature\ over\ 15\ (T_{over15}), Outside\ temperature\ under\ 15\ \ (T_{under15}), at\ hour\ t,$$

$$direct\ radiation\ daybefore\ \left(idirnorm_{daybefore}\right), horizontal\ radiation\ daybefore\ \left(idiffho_{daybefore}\right),$$

$$internalload\ daybefore\ including\ lighting, appliances\ and\ people\ (internalload_{daybefore})$$

The load is generated by one basis coefficient, and five regression coefficients and variables. The best fitting five variables are discovered by conducting regression analysis in the statistical data analysis software STATA. In the resulted regression formula the impact of the outside temperature, direct and horizontal radiation, and internal load including lighting, appliances and people are taken into account.

In order to take into account the fact that a single building behaves differently than a stock of buildings the three different electric heating load curves of the simulated offices are weighted and summed up. This profile is then used to describe the general direct electric heating profile in the offices.

The direct electric heating profile depends on the outside temperature and by using the regression technique the load can be defined for each temperature step (1 °C) over different seasons (summer, winter and transition). In order to present the electric heating load curve for the nine type days the prediction of the load profile for type days is conducted in the STATA. The load curves are presented in Figure 3.

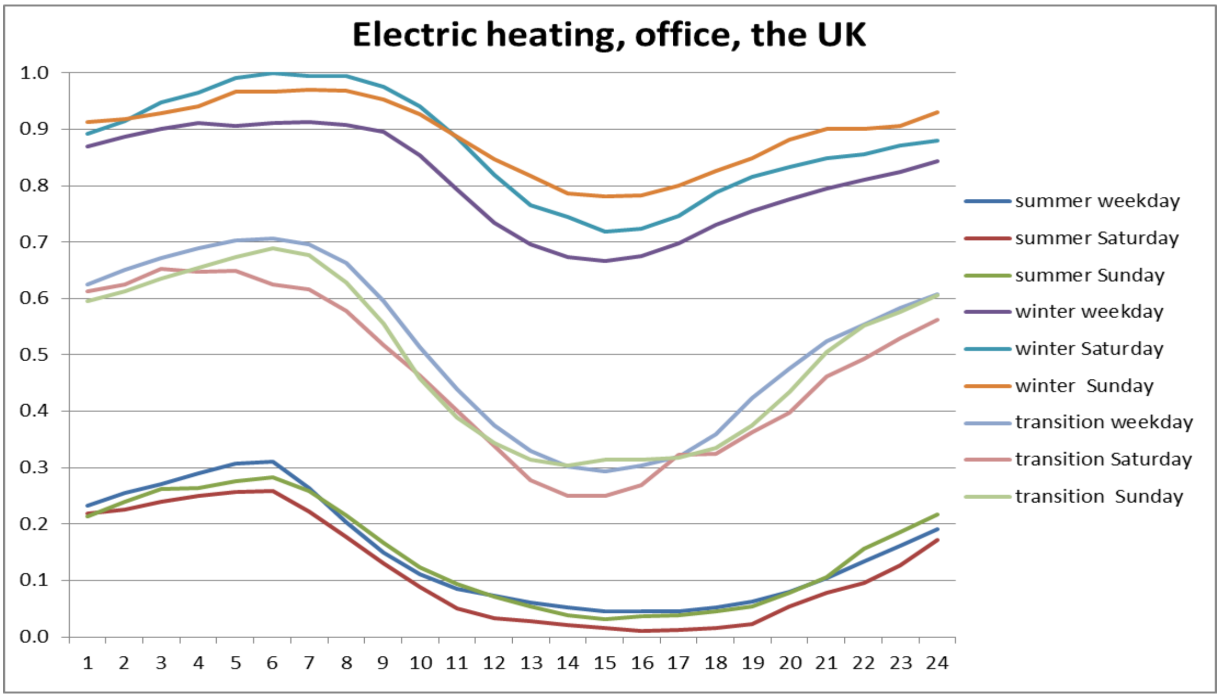

Figure 3: The direct electric heating profile based on the average UK weather data per type day.

The direct electric heating load curve in the office buildings in the UK for the nine type days is presented in Figure 3. In this case the building is heated without a night and weekend reduction. During the summer type days the load is the lowest. The load is generally at the highest point during the night time due to reduced internal gains, such as solar and occupancy heat gains. The load is highest during the winter type days as can be assumed and the transition type days are between the winter and summer.

The load curves in Figure 3 are strongly related to the outside temperature, which is defined as an average over a certain type days in a year. Due to this the type days do not differ from each other significantly.

In addition to the direct electric heating profile the lighting profile can be derived from the IDA ICE building simulation results by regression technique. In this case the regression formula has the following form:

$$L = \alpha_1 + \beta_1 x_{sch\_lighting} + Interaction\ terms$$

in which

$$L = Load\ of\ hour\ t$$

$$\alpha_1 = basis\ coefficient$$

$$\beta_i = regression\ coefficients$$

$$x_{sch_{lighting}} = Operation\ schedule\ of\ lighting\ (sch_{lighting})\ at\ hour\ t$$

$$Interaction\ terms$$
$$= interaction\ between\ the\ operation\ schedule\ of\ lighting, direct\ radiation\ and\ diffuse\ radiation$$

The load is generated by one basis coefficient, and four regression variables. Additionally, the interaction terms are taken into account. The best variables and interaction terms are discovered by conducting regression analysis in the STATA. In the resulted regression formula the impact of the lighting operation schedule and, direct and horizontal radiation are taken into account.

The derived lighting load profiles for different type days in offices in the UK are presented in Figure 4. The load is assumed to occur during the weekdays. At weekends there is only night load because the offices are mainly assumed to be closed. This profile is then used to describe the general lighting profile in the offices in different type days.

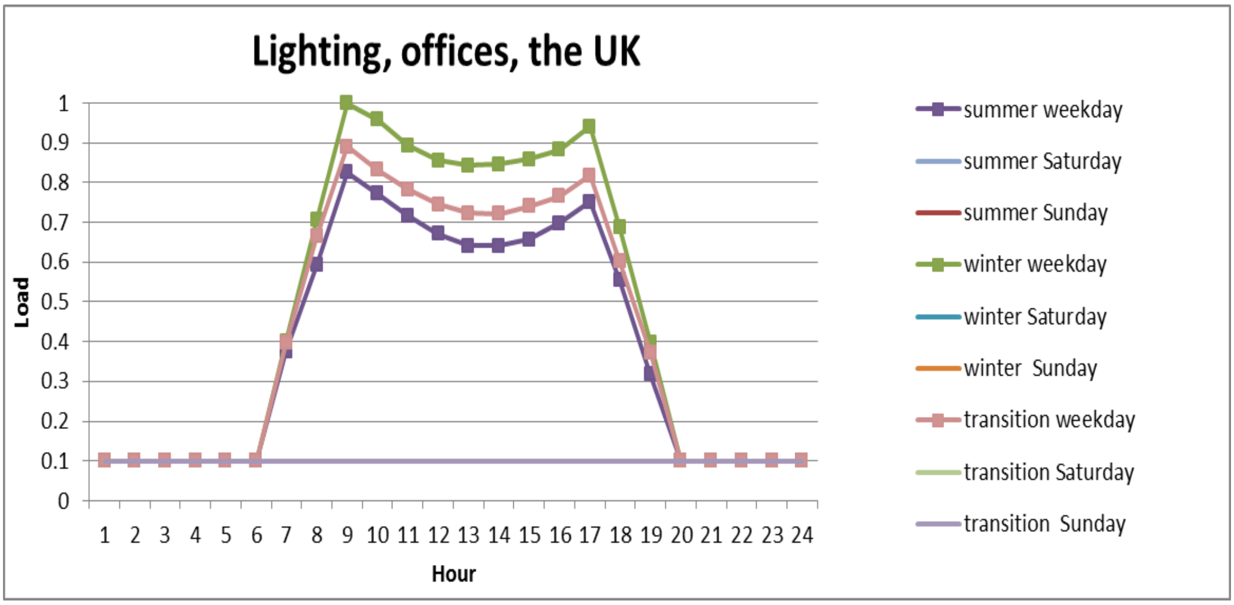

Figure 4: The aggregated lighting load profile for different type days in the offices.

In Figure 4 the similar decrease at midday can be discovered than in Figure 2 for the finance and public offices subsectors.

The results to generate the draft specific load profiles for electric heating and lighting are now presented. This section presents the Part 1 “Basic analysis” in the method process in **Figure 1**. The rest of the most relevant energy services are generated similarly based on the norms and standards.

Next the draft specific load curves are aggregated in the Part 2 and the global load curve is compared with the available external data from the Ofgem project in (30).

Aggregation and validation of the load curves

The aggregation of the draft specific load curves generated in the Part 1 is based on the information from the Forecast results. These results define the shares of the energy service specific consumption from the total consumption on a certain subsector. In this section the aggregation results of the finance subsector in the UK are presented. The energy service specific consumption shares are present in Table 1.

Energy service	**Share of the total consumption**
Lighting	27 %
Electric heating	8 %
ICT office	11 %
ICT data centers	14 %
Ventilation	16 %
Circulation pumps and other heating auxiliaries	8 %
Misc. building technologies	16 %

Table 1: The most relevant energy services and the shares of the total consumption based on the FORECAST-model results

In the first comparison of the generated global load curve on the finance sector in the UK to the external global load curve in (30) the decrease in the lighting profile at midday have too strong influence on the global load profile and the validation is not successful. In this case the iterative adjustment of the lighting profile is undertaken, such as in Figure 1 is described. The new lighting profile is based on the assumptions that the lighting is not shut down in the finance offices at midday and the energy saving measures are not undertaken so often. The adjusted lighting profile for the lighting on the finance sector is presented in Figure 5.

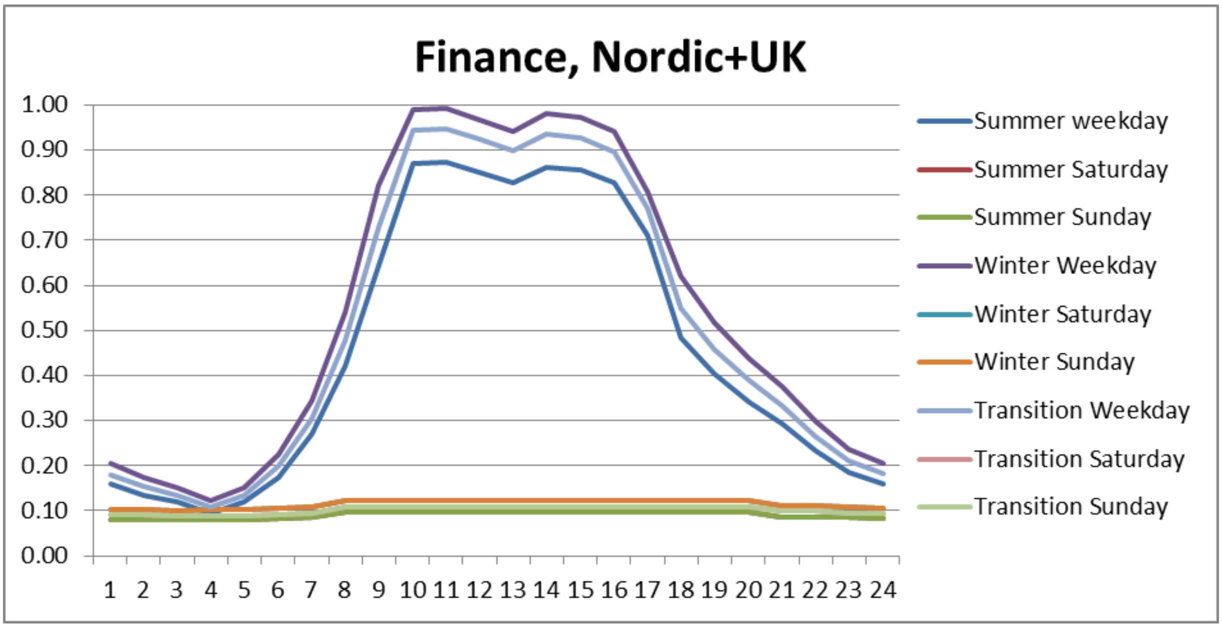

Figure 5: The hourly load profile of lighting in the finance sector in the UK

After the adjustment the aggregation is conducted again with the adjusted and already generated specific load curves. The validation is conducted again to the same external global load curve in (30) as before. The comparison between the generated and external global load curves is presented in Figure 7.

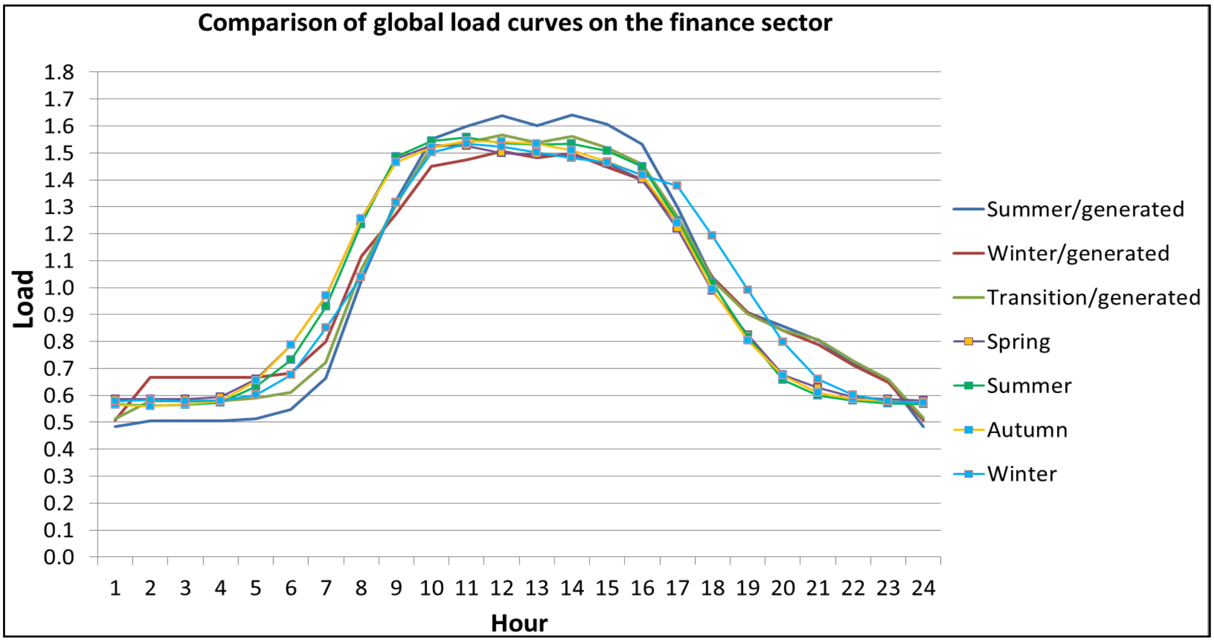

Figure 6: Comparison between the generated global load curves per type days and curves from the external source on the finance subsector.

The validation in Figure 7 is more successful than before the iterative adjustment of the lighting profile. However, there are still differences between the generated global load curve and the global load curve in (30). The external global load curve is generated from the measures on the commercial offices and the generated global load curve presents the finance subsector. The generated global load curve can be compared also to other sources. In Figure 7 there are presented the results of the descriptive analysis on the offices sector based on the measured electricity consumption data in the Smart Meter Electricity Trial data project issued by the Research Perspective Ltd and the University College Dublin, Ireland (27). The descriptive analysis is conducted for the measured electricity data from two hundred and ninety companies in Ireland. This analysis results in the global load curves of four subsectors on the tertiary sector for the nine type days. The comparison of the global load curve in Figure 7 and in Figure 6 show that the shape of the profile is similar on these office based sectors. However, in the Irish curves there is an electricity consumption reduction at midday, which does not recover back to same level. Additionally, there is more significant difference between the seasons in the Irish study than in the Ofgem-project data.

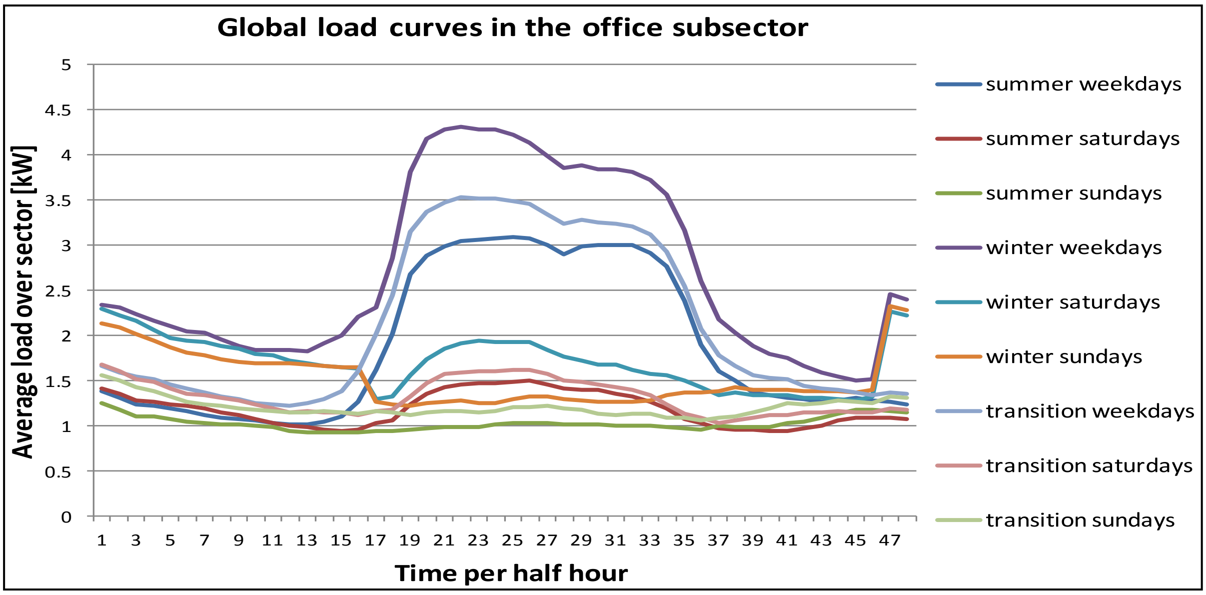

Figure 7: The global load curves of the nine type days per half hour in the office subsector based on measured data from SME companies in Ireland.

Additionally, the global load curves in Figure 7 are measured for small and medium enterprises, which might lead into difference between the profile shapes in Figure 6 and Figure 7.

DISCUSSION

There are different methods around to generate energy service specific load curves and aggregate them to present the global load curve of a certain subsector. In this paper the presented method to generate load curves is based on the already existing norms and standards, thermal building simulation results, measured electricity data, additional studies, and questioner surveys. By combining these different information sources the energy service specific load curves can be generated and aggregated to present the global load curve of a certain subsector and finally, the whole tertiary sector. Additionally, the generation can be extended to different European countries if the required information or simulation results are available from the required country.

The results of this paper present an example of how to generate energy service specific load curves based on the information around and without expensive and time consuming electricity consumption measurements. The measured data is used in the validation process but it can be provided from the already existing studies. The comparison of the generated energy service specific load curves with external measured data has shown that generic load curves have a reasonable shape and the used method is useful.

Mainly the results prove that the energy service specific load curves are possible to derive based on the information from the thermal building simulation, standards and norms, and measured data from the external sources. Finally, linking obtained load profiles with detailed bottom-up models allow forecasting the aggregate load curves of the tertiary sector.

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Assessing the Energy Consumption of Hospitals through Simulation and Measurements

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Abstract

Like many other commercial buildings, hospitals offer a considerable potential for energy savings. This is due to oversized systems, non-ideal operating conditions and other aspects. However, the complexity and diversity of consumers and systems as well as a lack of data make it difficult to evaluate the energy performance and estimate saving potentials.

One option for the assessment of energy conservation measures is the realization of a building energy simulation. This can help to get a better understanding of the distribution of energy consumption throughout the building as well as the effectiveness of different energy saving measures that can be “tested” in the simulation.

In a project of Fraunhofer UMSICHT a dynamic building energy simulation tool is created. The tool is designed in Modelica, a modeling language that is well suited to model complex buildings due to its object-oriented nature and flexibility. The model is built in a modular way: typical energy-relevant elements of a hospital are identified and pre-defined. Outputs of the model are for instance electricity or heating energy demand of the building. The tool is then deployed and tested by simulating two different hospitals.

In order to collect input and validation data, comprehensive measurements are carried out. Since information about energy consumption of medical equipment as well as information about usage schedules of equipment is rare, numerous short-time measurements at equipment and department level are realized. Together with measurements at plant level they serve as input data for the model and provide information about the composition of the energy consumption.

Measurements of electricity and thermal energy consumption are used for validation and calibration. Simulated results of subcomponents and the entire model are compared with real building consumption data to ensure that the calculated results represent the building in an accurate way.

Introduction

While it is difficult to assess the proportion of energy use of buildings since they are usually not explicitly distinguished in energy statistics, it is clear that buildings are responsible for a significant fraction of global energy consumption. In developed countries, residential and commercial buildings together consume 20-40% of the total energy. This is more than is needed in the other sectors industry and transport respectively [1]. The Energy Information Administration EIA predicts a further rise in building energy consumption [2]. Factors for this include population growth, higher levels of supply technologies and comfort, more time spent inside of buildings as well as a higher demand of services due to economic growth. The rise in energy consumption is especially significant for Heating, Ventilation and Air Conditioning (HVAC): In the United States, 50% of building energy use is due to HVAC-systems, and these numbers are similar for other industry nations [1]. About one third of building energy consumption is caused by commercial buildings [2].

Considering the slow turnover rate and the long lifetime of buildings, in order to reduce building energy consumption in a timely manner, not only energy efficient new constructions, but also retrofit of existing buildings is necessary. One of the main prerequisites for successfully choosing energy efficiency measures is knowledge about energy usage and the factors influencing it. In many buildings, especially the more complex commercial buildings, little of this knowledge exists [3].

One building type with high energy consumption and high savings potential are hospitals. Due to their high energy intensity, they account for a significant fraction of commercial building energy use [4]. In recent years, energy efficiency in hospitals has increasingly gained attention. Still, there is little scientific research going on about hospital energy use and overall little data exists. This makes it difficult to identify energy saving options.

In a project by the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT simulation of two hospitals are undertaken in order to gather information about the interactions of energy flows within hospitals and to identify savings options. A model is currently being developed in the multi-domain modeling language Modelica which will be used for the simulations. Comprehensive measurements reinforce the analysis.

In the following, a review of energy consumption and energy efficiency in hospitals is presented, followed by an overview of methods for the assessment of buildings. The model by Fraunhofer UMSICHT is introduced as well as some first experiences, validation results and compilation of input data based on measurements.

Energy Consumption in Hospitals

First, an overview of the energy-relevant but not energy-related background is given, followed by a description of energy use in hospitals. The chapter concludes with information about the potential for energy reductions in hospitals.

Hospital Background

Hospitals are subject to many changes during their lifetime. While being built for a lifetime of 50 to 100 years, during this time many changes in the medical field, the layout of departments, etc. occur [5]. This is partly due to changing conditions and focus in the healthcare sector. The non-stationary sector is growing more and more important and hospitals offer more ambulant treatments. Psychiatric case numbers increased by more than 100% during the last ten years [6]. More and more, hospitals are becoming health centers with many diverse offerings for patients [7]. Equipment that used to be centralized (e.g. x-rays) is now distributed among the hospital [5]. Along with necessary refurbishments and modernizations these developments lead to constant changes of hospital structure and equipment.

The great majority of hospitals are in a difficult financial situation. Even if running costs can be met, investment capability is low [8], [9]. Between hospitals, there is a lot of competition, patients compare services and choose hospitals accordingly [8].

Hospitals have to meet criteria and guidelines and thus reach a quality standard in construction and operation that is somewhat comparable [7]. Especially for ventilation and air-conditioning design and operation are governed by multiple guidelines and standards. Due to the continuous operation of the hospital, run times are longer than in other buildings. High air flow rates are required and equipment has to fulfil high reliability and hygienic standards.

Energy Consumption

Hospitals use an enormous amount of energy. This is due to energy-intensive equipment and high equipment density, 24h-operation as well as high air volume flow rates for ventilation. Consequently, one hospital bed alone uses about the amount of electricity as two single family homes [10]. The consumption of a larger clinic is comparable to that of a small town.

Although energy costs constitute to only about 3% of total hospital costs, the absolute numbers are significant and will become more and more important with rising energy costs [10]. Average expenditures of German hospitals in 2012 were 1 Mio. € per year for energy, fuel and water [11]. Although heating requirements are expected to decrease in the future, cooling needs will increase due to more high-tech equipment [12].

Several benchmarks exist that compile energy data for different hospitals. They can help to compare single hospitals with others and identify areas where improvements are possible. Mostly, total consumption of thermal energy for heating and electrical energy are given with respect to area or number of beds (see e.g. [13], [14], [15]). In some cases, the hospitals are grouped by number of beds or type of hospital in order to create higher comparability of data. Still, the high variability of hospitals diminishes the significance of these comparisons. A hospital with higher-than-average consumption can still operate very energy efficiently, with the higher use intensity being due to a greater number of energy intensive equipment. Figure 1 illustrates the broad range of hospital energy consumption in US-hospitals, as well as the higher energy intensity of hospitals compared to other buildings.

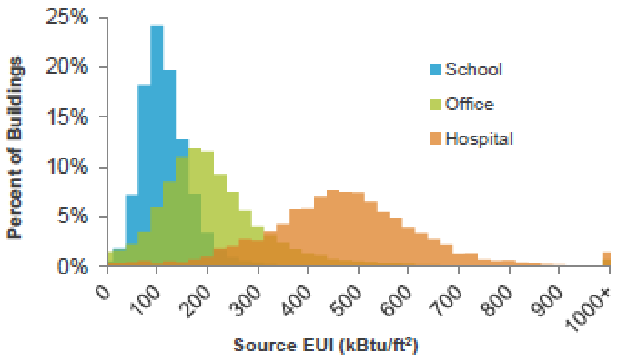

Figure 1: Energy use intensity (EUI) of US-hospitals in comparison to other building types [16]

Higher resolution data could help with that problem. Accordingly, in [17], measurements in specific areas in twenty hospitals, including for example ventilation of operating rooms and elevators were undertaken. The Californian benchmarking CEUS breaks data down to end use energy for lighting, heating, cooling, etc. [5]. However, few of these detailed benchmarks exist and with no additional measurements it is difficult to gather these data for the existing hospital stock.

Energy Efficiency

There is a great potential for reduction of energy use in hospitals. Due to obsolete technologies and buildings structures as well as oversized systems, many hospitals consume more energy than would be necessary [12]. Reduction of energy consumption is especially important in the context of the rising energy costs and the hospital cost pressure.

The main purpose of healthcare buildings is the provision of medical care; energy efficiency is usually not on the top priority list. Competition is decided not because of energy efficient operation but because of the medical services provided. Therefore, hospital layouts are designed to allow for maximum efficiency of medical activities, not energy efficiency; actions of staff can lead to inefficient operation [5].

The aforementioned financial situation also does not always allow for investments in energy efficiency; necessary modernizations are put off and lead to inefficiencies. In many cases, no investments in energy measures can be afforded even if this would reduce costs in the long run.

Oftentimes, the technical staff is not trained to identify savings options or simply do not have time in between day-to-day routine. Since the functioning of systems is critical to the 24/7-operation and safety of patients, sometimes inefficient operation is accepted as long as the equipment functions in the intended way. In order to ensure security of supply, systems are typically overdimensioned. The complex nature of energy provision in hospitals also complicates the easy identification of inefficiencies.

When changes to hospital layout and equipment occur, as happens regularly, often plant sizing and operation are not adjusted. This leads to non-optimal design and operation and therefore to inefficiencies. Decreasing energy demands due to outsourcing of services as well as different consumption patterns again cause oversized systems.

In a survey by Ernst&Young [8], 150 German clinic managers were asked in which areas they are planning to implement cost saving measures. The top answers were “medical goods/materials”, “maintenance and repairs” and “personnel”. Only 3 % were planning to reduce energy costs. This way, a great potential for cost reductions is resting unused. Several studies reveal a potential for reductions of energy costs of up to 40% [10], [12], [13], [18].

Figure 2 evaluates the measures implemented in 42 hospitals with a successful energy reduction campaign. The data is based on [19], [20]. It can be seen that about 70% of the hospitals implemented measures affecting the heat generation. About 80% of these installed a combined heat and power plant. Over two thirds of the considered hospitals invested into reduction of lighting energy, mostly by using energy efficient lighting and installing motion and presence detectors. 64% of the hospitals established measures in ventilation and air conditioning, mainly by installing efficient, speed-controlled fans and heat-recovery systems or changing settings and operating times. 40% improved the efficiency of refrigeration for example by replacing chillers and installing heat recovery systems [19], [20].

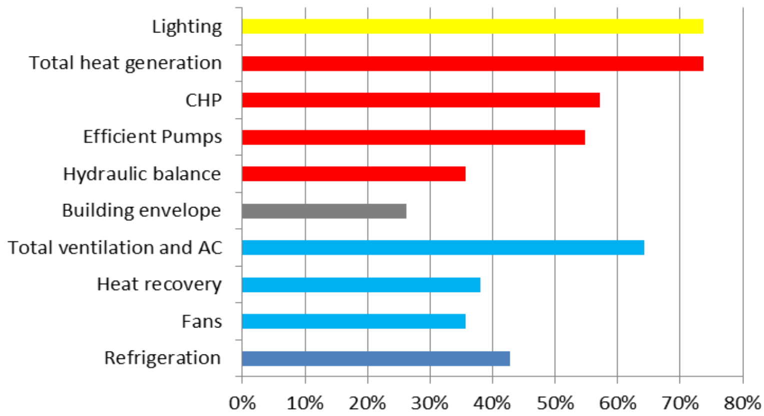

Figure 2: Percentage of hospitals that implemented the specified measures as part of their energy reduction strategy

The examination of hospital energy use and the identification of effective measures are complicated by the lack of data. Often, only billing data are available to judge the energy performance. Especially in older buildings, few submeters are installed and fewer are logged automatically. In literature, very little higher detail data that exceeds global energy consumptions is available. Basically no data exists about load profiles of medical equipment or system level energy use [5]. While medical equipment contributes for about 20-30% of energy use, few studies give attention to energy efficiency of medical equipment [21].

Building Energy Assessment

There are different methods for the energy assessment of buildings, including calculation-based and measurement-based methods or combinations of both.

Measurements are the basis of any energy audit. In order to identify effective savings options, knowledge about the energy flows and the distribution of energy consumption throughout the building is inevitable. Furthermore, measurements are the only way to quantify savings and to get feedback on the effectiveness of implemented measures.

The minimum available data is billing data – total consumption of fuels and electricity provided by the utility. In combination with benchmarks a first idea of the efficiency of the building can be gained. To specifically determine sources of inefficiencies, additional resources are necessary. Most hospitals will use some kind of building control system that has the ability to log data. These can be used to verify correct operation and set-points and to monitor system performance. Additional short-term measurements can be undertaken to examine system efficiency. Accuracy depends on the measurement method, the equipment and the actual conditions at the site and should always be considered. With measurements alone, no predictions for energy consumption after the occurrence of changes (refurbishments, energy saving measures) can be made.

A calculation-based method allows the computation of energy performance of buildings and their auxiliary systems. It calculates thermal conditions in buildings and the energy required to maintain these conditions [22]. Mostly, it is applied during design in order to evaluate different design options and to predict energy performance, but it is also used to determine compliance with regulations and rating systems or to compare different energy saving options during operation [23]. A wide variety of tools exists for different purposes and with different detailing [24]. The calculation method can be static or dynamic [25]. Dynamic simulations are more complex than steady-state calculations, leading to more accurate results. All the same, this also causes lower robustness and programs require more complicated handling and higher detail input information [26].

When it comes to understanding energy consumption in complex commercial buildings, DeBaillie [27] states that people's intuition is often misleading. It is usually based on the simpler interactions in residential buildings that they know from experience. However, there are fundamental differences between one-zone residential buildings and mechanically ventilated, multi-zone commercial buildings that possess higher interior areas and use complex HVAC-systems. Applying the same concepts to residential and commercial buildings will lead to different results. Building energy simulation can show the effects of these complex interactions that are not easy to grasp intuitively.

Nevertheless, simulation results are invariably subject to uncertainty and the more so the more uncertainty there is in the input parameters. Therefore, by combining simulation with short-term measurements, simulation results can be made more reliable. Many otherwise unavailable input data, which would be based on assumptions, can be measured. This includes for example temperatures, internal loads, system parameters, etc.

Even so, many input parameters will still be uncertain to some extent and can cause a great deal of variation in the output. This applies for example for parameters of the building envelope that vary due to age, temperature, quality and maintenance or are generally difficult to estimate like infiltration rates. User behavior also brings variability; the same is valid for equipment that does not operate in the intended way. Some inputs will always be based on assumptions and rules-of-thumb. A generally accepted method to find the 'best fit' input parameters is model calibration with measured data. Calibration means the process of using available information to adjust the unknown or uncertain input parameters in a way that the model output reflects the true operation of the building. Also, by examining differences between model and measured data, often problems in the real building are detected [22].

Method

The proposed method consists of a combination of short-term measurements and simulation. As many hospitals do not have access to detailed data, measurements are essential to get an impression of the energy situation of a hospital. Measurements alone can already provide useful information and detect inefficiencies. In combination with a simulation, more detailed information can be accessed and predictions for energy consumption after retrofit are possible. The following four steps are proposed for the assessment of hospital energy performance.

1. Data acquisition, additional short- or longer term measurements where no data is already available
2. Modelling and simulation of the hospital
3. Calibration of the model with measured data to match simulated with actual results
4. Identification of effective points for energy savings

Since so far few detailed simulative investigation of hospitals have been undertaken, valuable knowledge will be gained from the simulation and measurements. The simulation will provide detailed information about energy distribution in hospitals as well as an in-depth analysis of energy dynamics and dependencies.

Model

The tool used for the simulation is currently being developed at Fraunhofer UMSICHT. The intention was to create a robust and easy to use tool for the energetic analysis of existing multi-zone buildings. Information about the distribution of energy consumption is provided by the tool and from this possible energy saving options can be derived. By varying parameters or changing objects, the effect of different energy efficiency measures can be tested. The required inputs are oriented at data that are typically available in hospitals. The tool is not intended to support design decisions, therefore e.g. no contaminant tracking or human comfort analysis is included in the scope of the model.

The tool is developed in the object-oriented language Modelica. Modelica is an equation-based and object-oriented modeling language. It was developed in order to create a language that could be used to model a wide range of systems from different engineering fields. Modelica solves sets of differential-algebraic equations that describe the relevant system [28]. Due to its flexibility and suitability, in recent years Modelica has been used increasingly for building energy simulation [29].
The implementation in the simulation environment Dymola provides a graphical user interface that simplifies the application. The modular structure allows for simple changes and subsequent implantation of new models.
The developed library contains submodels for the elements of the building envelope, weather data, user profiles and building systems.
In an integrated approach, loads and building systems are calculated simultaneously. Thermal load calculation is done using a heat balance approach for each thermal zone, represented by a room model with uniform temperature. Equipment models are based on thermal balances or efficiency curves. The thermal energy distribution is calculated using simplified factors. Hydraulics are not considered, since the detailed information about the piping layout is rarely available for the complicated distribution network of hospitals.
Figure 3 shows a schematic representation of the model. Different submodels for thermal zones and HVAC equipment are connected to represent the actual building. Input data comprises mainly weather data, information about building geometry, information concerning the building envelope (U-value, window parameters), schedules for occupancy, lighting and equipment as well as data about type and operation of the technical plants.

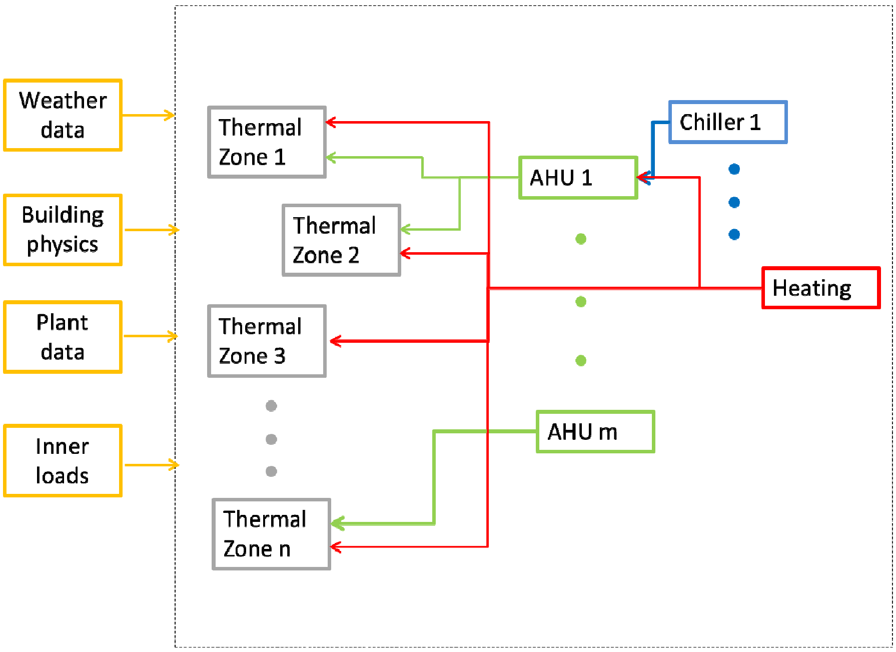

Figure 3: Schematic diagram of the building model

The results include heat flows at different levels of the building, e.g. annual heat consumption, annual electricity consumption, load profiles for heat and power as well as end uses. By changing different parameters, their effect on consumption can be seen and thereby the effectiveness of different measures can be calculated.

Data sources

Data has to be collected in order to provide inputs for the energy model and to be used for validation/calibration. Consumption data is derived from a building control system with already installed sensors as well as additional measurements. If the usage pattern is not weather-dependent, short-term measurements of one week are considered as sufficient. For weather-dependent

consumptions, if possible, measurements are conducted over longer periods of time or are repeated for significant periods of the year.
System level measurements include heat flow measurements on boilers and combined heat-and power (CHP) plants. For refrigeration, heat flow and electric power measurements are conducted on chillers and the recooling system. Heat flow measurements at heating and cooling coils and heat recovery systems and electric power measurements on fans serve for the investigation of ventilation and air conditioning systems.
Equipment level measurements include electric power measurements of the heat and cold circuit as well as measurements of electric consumption at subdistribution level.

Single equipment that accounts for a significant portion of energy use, either due to its number throughout the hospital or due to the high consumption, is measured as well. The load profiles give information about installed power and usage times.
Finally, meteorological measurements of ambient temperature, relative humidity and global radiation throughout the whole examination period provide data on the climate on site and serve as input for the simulation.

Application to Partner Hospitals

Until now, the model has been developed and validated with measured data from two hospitals. So far, smaller simulations and validations of submodels have been realized. A great amount of input data has been collected and processed, some of which is presented in the following.

Experiences with Measurements

Measurements need lots of planning ahead. Installing and uninstalling of instruments need up to a day. Handling, processing and evaluation of data will take another day. Within the building it is necessary to be accompanied by technical staff. The feasibility of measurements depends on the situation at the site. Measuring points need to be accessible and save for installing an instrument for a minimum of a week. Measurement accuracy also depends on the conditions of the site. A prior walk through is therefore indispensable.

As with many older buildings, few data already exists in the two examined hospitals. Both buildings possess a central building control system, but not all measurement points are logged. The newer implemented heat generators are equipped with meters. However, concerning the energy consumption of different departments or specific equipment of the building, no information is available.

Due to frequent alterations of the building structure, existing plans are not always accurate. This applies amongst others for the heating network and for electrical infrastructure. Therefore, with all measurements it is invariably important to review the results with common sense to verify they display the consumption that was intended to be measured.

Validation of the Chiller Model

Exemplarily for the validation of different submodels, the validation of a compression chiller is shown in the following. The model is based on Coefficient of Performance (COP)-curves with respect to the temperatures of the chilled water and the recooling circuit. The curves were built from manufacturer's data for each chiller type respectively. The model also contains a submodel for the recooling circuit and the cold storage tank that represents either an actual tank or the storage capability of the distribution system. The cooling energy is provided from this tank. The demand is calculated by the thermal zone models and the air conditioning model. The chiller model is controlled by the mean temperature of the tank. If a certain value is exceeded, the chiller is switched on or is shifted to a higher power level. Instead of calculating the cooling demand by the demand side models, measurements of the cooling demand can be integrated. That way the chiller can be simulated separately from the rest of the building. This was used for the validation.

A chiller that serves the operating rooms of a hospital was chosen for validation. Measurements of the cooling energy provided by the chiller were used as input for the model. Figure 4 shows the results of the validation; measured and simulated electrical power and energy of the chiller are compared. While the cycling of the chiller is not exactly represented by the model, the energy consumption of the chiller is reproduced adequately for the first 20 days. For the last 8 days, a deviation between the measured value and the simulated value occurs. Since until then the simulated results matched the actual results very closely, it is suspected that some operational parameters were changed. After repeating the simulation for the last days with a higher temperature of the chilled water, the measured results matched again closely the simulated results; therefore this seems a likely explanation for the divergence.

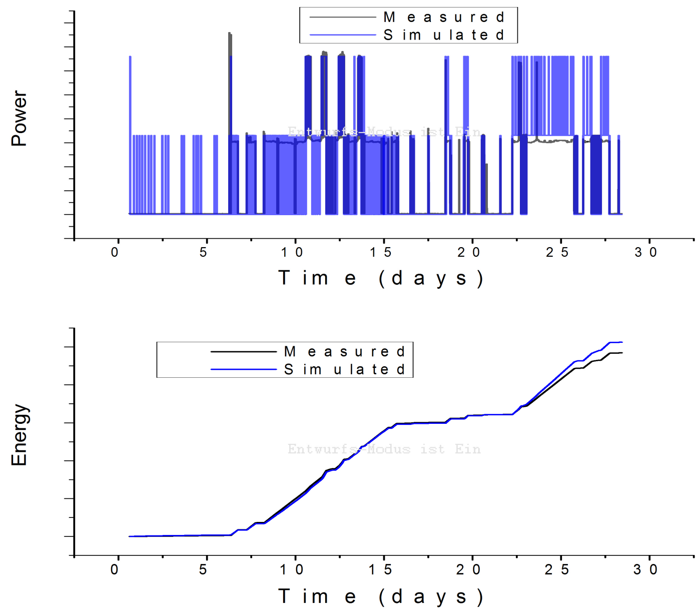

Figure 4: Comparison of measured and simulated electrical energy consumption for a compression chiller

Similar validations were undertaken for models of the air handling units. They consist of several submodels for the fans, heating and cooling coils and heat recovery systems. The measured data results from different air handling units in one hospital. The survey points were chosen for representativeness and ease of measuring. A weather station on the roof of the hospital provides data on air temperature and humidity. Validation showed that results provide the desired accuracy, provided sufficient and correct input data is available.

Department- and Equipment-Level Measurements

Hospitals contain many rooms with highly diverse energy profiles. There are 24h-hour-operated wards, highly energy-intensive operating theatres, kitchens, a central sterilization plant that is run in a three shift operation, regular office rooms, etc. Developing load profiles for the different areas as an input for the model is not an easy task. For office buildings, the commercial building type that has received most intention from energy modelers so far, many studies examine equipment loads, user behavior and triggers of energy consumption. For hospitals, few of such detailed examinations exist.

To gather information about consumption patterns of equipment, energy loggers were distributed in one of the hospitals to measure single smaller consumers. Focus was on multiply occurring equipment that has an impact on energy consumption by its numbers. Room lists and equipment lists were used to identify these items. Typical equipment for representative room types is compiled and the averaged measured consumptions summed up to develop load profiles for these room types. They will later serve as an input into the energy model. Electric measurements of entire departments are used to validate these room profiles. The profiles are normalized with the specific power data of the equipment and can thus be adapted for rooms equipped with different devices.

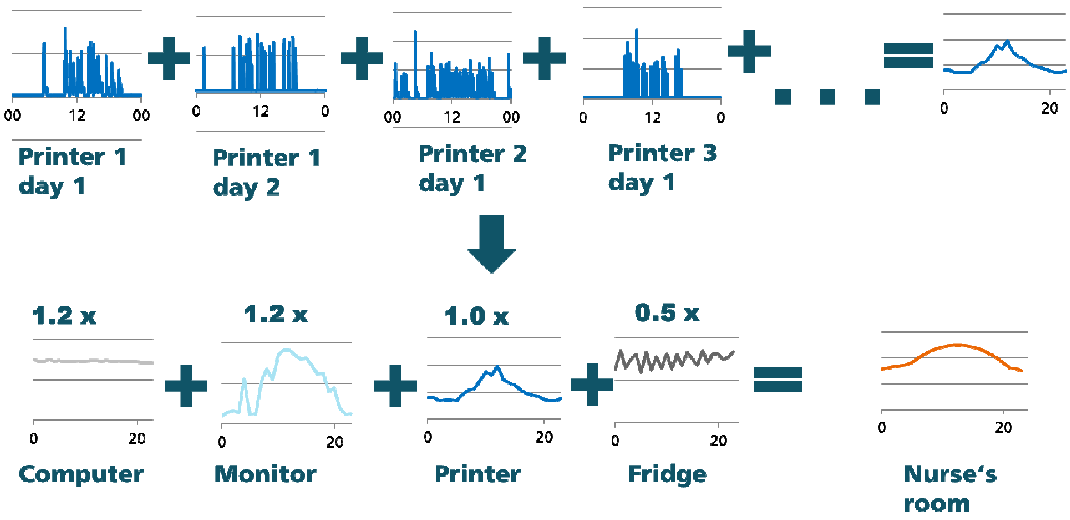

Figure 5: Synthesis of averaged day profiles for a printer and a nurse's room from measured data

To clarify the procedure, Figure 5 shows an example of the compilation of profiles. In the upper part, the generation of a load profile for a printer is shown. The measured profiles for each single day are summed up for each printer and divided by their number. Together with other similarly generated profiles, this is used to generate the profile of different room types, in this case a nurse's room. In the examined hospital, nurse's rooms are equipped on average with 1.2 computer workplaces and one printer. Half of the nurse's rooms additionally contain a fridge.

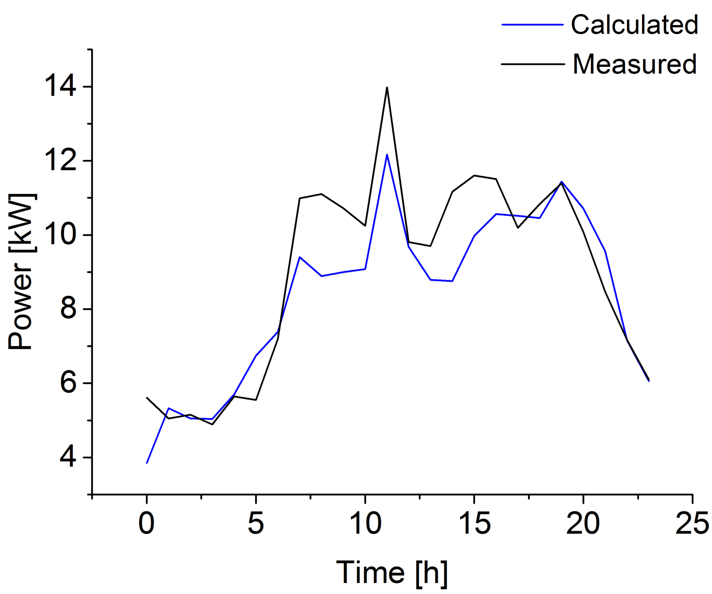

Figure 6: Comparison of measured and synthetic profiles for a hospital ward

In order to validate these profiles, room profiles are added up to generate consumption patterns of specific departments. These are then compared with measured consumption of the departments. In Figure 6, the measured consumption of a ward with about 1,300 m², containing twenty patient rooms, one nurse's room, two smaller kitchens, three treatment rooms and several other rooms is compared to the synthetic load profile of this ward, built up from the respective room profiles. The calculated profile underestimates the total consumption by about 6% (214 kWh/day vs. 201 kWh/day). While during the night, the consumption is adequately represented, some equipment that operates between 7am and 5pm seems not to be accounted for by the calculated profiles.

All in all, since the profiles are averaged, there will always be a difference to the actual equipment of the ward in question. Considering this, the averaged profile matches the measured consumption well enough to provide load profiles if measurements are not feasible.

Load profiles are created only for rooms that are occurring repetitively throughout the hospital. This includes hallways, patient rooms, nurse's rooms, offices, etc. Other departments like central sterilization unit, kitchen, operating theatre or high-consuming equipment are measured as a whole.

One major single electrical consumer is the magnetic resonance imaging (MRI) scanner. As seen in Figure 7, energy consumption during one week is about 2 MWh, leading to a consumption of more than 100 MWh per year. This value does not include the cooling and ventilation needs.

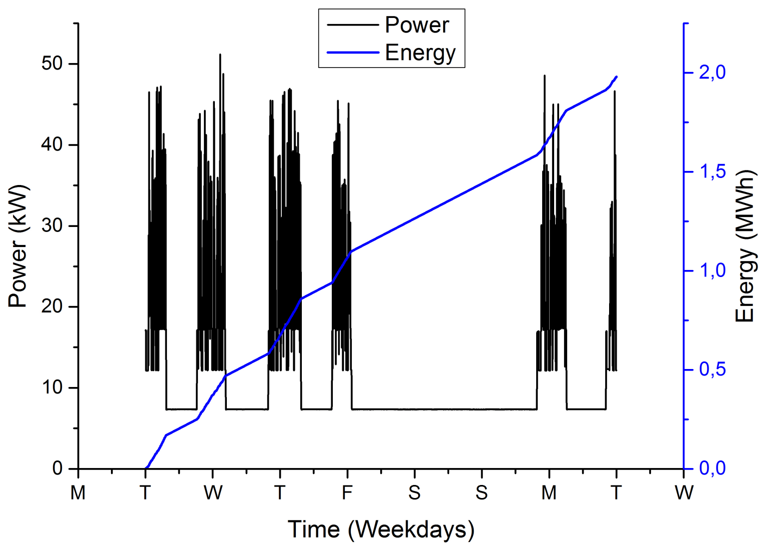

Figure 7: Electric load profile for an MRI-scanner

Another typical consumer with high loads are the operating rooms. Figure 8 shows the measured consumption for several weekdays and weekend-days and the averaged profiles for four operating rooms and associated rooms in one of the examined hospitals. These numbers are then again summed up for every hour of the day to filter out the smaller fluctuations.

Investigation of further submeters shows that about half of the electric consumption of the operating rooms is due to lighting.

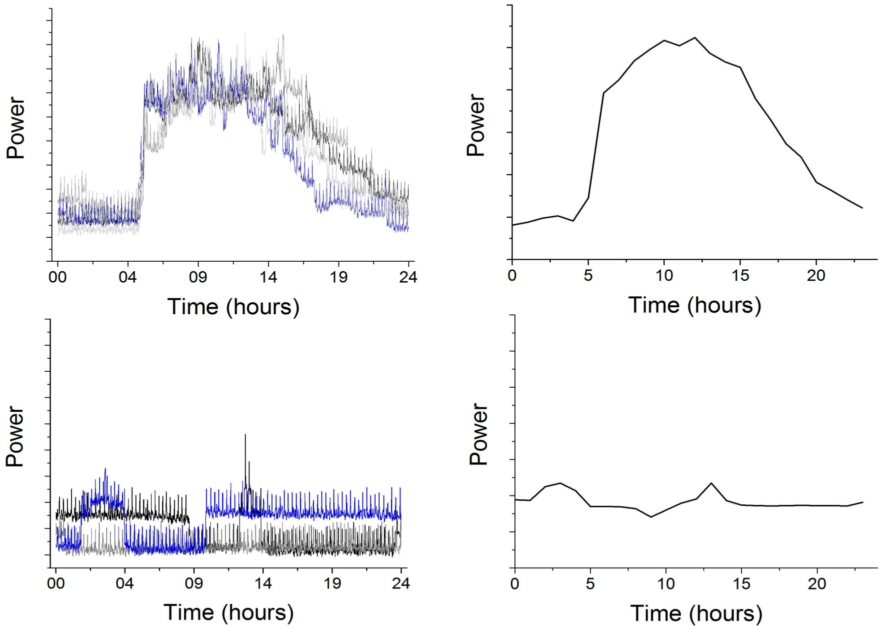

Figure 8: Measured and averaged day profiles of an operating theatre
Left: measured, right: averaged, top: weekday, bottom: weekend

The profiles for the different rooms are used as inputs for the simulation. Hourly values for weekend and weekday profiles are provided and used as a default profile for the respective room types throughout the hospital.

Summary and Conclusions

With more and higher detailed information about the energy flows in a hospital and the factors affecting them, it is easier to identify savings possibilities. As a method to assess energy consumption, a combination of measurements and simulation is proposed. While a dynamic building performance simulation can provide highly detailed information about a building, it also needs comprehensive input data and results are subject to some uncertainties. Measurements at different buildings and systems levels help to produce more accurate simulation results.

An exemplary validation of a chiller model was presented in this paper. Since few input data about consumption profiles of hospital rooms exist, several measurements and the compilation and processing of the data to be used as input into the model were shown.

So far, the model has been developed and smaller simulations were undertaken. In a next step a simulation of a whole hospital will be done and a sensitivity analysis will provide insight on the most important parameters that influence energy consumption. This will serve both for the calibration of the model as well as information about where best to implement energy saving measures. Experiences from the application will be used to continuously improve model accuracy and application.

Since such a detailed simulation and comprehensive measurements as implemented in the scope of this research project may not always be feasible for practical applications, recommendations for an assessment with a reduced complexity will be provided.

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An Analysis of Energy Consumption and Occupant Behaviour of an Academic Building

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Key words: electrical consumption, university building, room occupancy

Abstract

Buildings are responsible for approximately half of the total UK CO_2 emissions and UK universities are amongst the most significant consumers of energy. A pilot study was undertaken to analyse the relationship between the energy demand profiles and user activities to ascertain the performance of a university building in terms of electrical consumption. Some of these activities include an understanding of the continuous and stand by electrical appliances in use, the usage of lighting, and the usage of meeting and class rooms and the building management strategy.

Half-hourly electrical demand data for the case-study building was gathered through a data logger and provided by the university estates department. An online questionnaire was designed and circulated to members of staff and students to understand energy consumption patterns. A face to face interview was also carried out with the building manager to gain insight into how the building is managed on a daily basis.

It was found that the building was mostly controlled by a building management system (BMS) and that occupant control was mainly restricted to the use of localised lighting control, personal computers/printers and some of the kitchen appliances. The shape and magnitude of energy demand profiles shows a significant trend which does not seem to be strongly connected to occupancy patterns. Obtaining good information is often the crucial factor in determining the quality of a design. The outcomes of this work should provide a base to further develop a robust model that incorporates factors such as human behaviour aspects to predict energy consumption.

Introduction

The UK government is committed to an 80% reduction in CO_2 emissions by the year 2050 [1]. Building energy use currently accounts for 46% of the total UK energy consumption and is responsible for approximately 47% of the total UK CO_2 emissions [2]. Non-domestic buildings account for 19% of the total UK carbon emissions and thus this is an area where substantial reductions can and should be made.

Universities in the UK consume significant amounts of energy in the form of electricity and natural gas [3,4]. According to new legislation passed in April 2010 [5], most of the UK's colleges and Universities are now required to report on their energy use and improve their efficiency. A performance gap seems to exist between the way buildings perform and what is expected of them in terms of energy consumption. Advances in technology are increasing to achieve the desired reduction in energy consumption goals but this does not necessarily lead to an overall reduction. The manner in which building occupants behave and interact with the building also has a massive impact on the energy used and the comfort levels achieved. The PROBE (Post-occupancy Review of Buildings and their Engineering) studies conducted between 1995 and 2002 [6] investigated the performance of 23 non-domestic buildings concluding that the actual consumption was usually twice as much as predicted.

According to Carbon Buzz, on average, buildings consume between 1.5 and 2.5 times predicted values [7]. Some researchers have shown that the measured electricity demands are approximately 60% to 70% higher than predicted in both schools and general offices, and over 85% higher than predicted in university campuses [8].

Data on energy supply and end use are a pre-requisite to developing policies and initiating a change towards energy efficient and sustainable buildings [9]. Practically, energy consumption in non-domestic buildings is a very complex organisational issue due to a number of factors involved brought about by the varied levels of activities that take place. In the case of a university building this may include lecturing, research, administration, cafeteria and leisure. A dilemma therefore exists in terms of energy consumption: on the one hand, to consume energy to satisfactorily meet the energy needs of occupants and maintain comfort standards and on the other hand, to minimise energy consumption through effective organisational energy management policies/regulations. [10].

In the UK the National Calculation Method (NCM) is a procedure for demonstrating compliance with the Building Regulations for non-domestics buildings. The NCM models the annual energy use for a proposed building and compares it with the energy use of a comparable “notional” building, to produce an “asset rating” in the form of an Energy Performance Certificate (EPC). EPCs present the energy efficiency of buildings on a scale of ‘A’ to ‘G’, with ‘A’ being the most efficient and ‘G’ the least. The modelled energy use however, does not consider the areas of organisational energy management policies/regulations and human factors (i.e. energy users’ behaviour) which are very important elements influencing office building energy consumption [10].

A pilot study was undertaken to understand the reasons for the gap that exists between the modelled/predicted and measured energy performance of a university building. An empirical approach was adopted to assess energy use in the case-study building. This paper focuses on mapping the pattern of daily electrical consumption of the case study building against the daily room activities/occupancy.

Methodology

Case study Building

The Post Graduate centre (Figure 1) is located on the main campus of Heriot-Watt (HW) University, Edinburgh, Scotland. The centre provides both educational and social facilities and also allows the delivery of a continual professional development programme. The choice of case study was determined by the following factors:

- Availability of electrical consumption data at a half hourly resolution from the Estates department
- Newly constructed building with an EPC rating of ‘D’ with potential to improve to D+ based on the recommendation of installing solar water heating, building mounted wind turbine and PV.
- A multipurpose building, in addition to teaching and research it also provides other services

The area of the building is approximately 2,000 m^2 and is the winner of an architectural competition for an 'iconic' building [11]. The floor plan is shown in Figure 2. The building houses 12 office spaces for staff members, a lecture theatre (PG G01), two seminar rooms (PG 201, PG 202), three meeting rooms (PG 301, PG 302, PG 303), a café, social space and study space. The building has four floors and three distinct zones. The south zone contains a cafe, offices and smaller seminar and meeting rooms requiring good day lighting, natural ventilation and minimal mechanical systems. The central zone houses vertical circulation, toilets and stores. The north zone accommodates larger spaces, many requiring limited or no day lighting and all requiring mechanically controlled environments. At the east end of the central zone, located next to the entrance is the main stair, enclosed in glass allowing diffused daylight to flood into the central atrium. A lift rises up through the atrium serving all floors. [11]

Figure 1 The Post Graduate centre

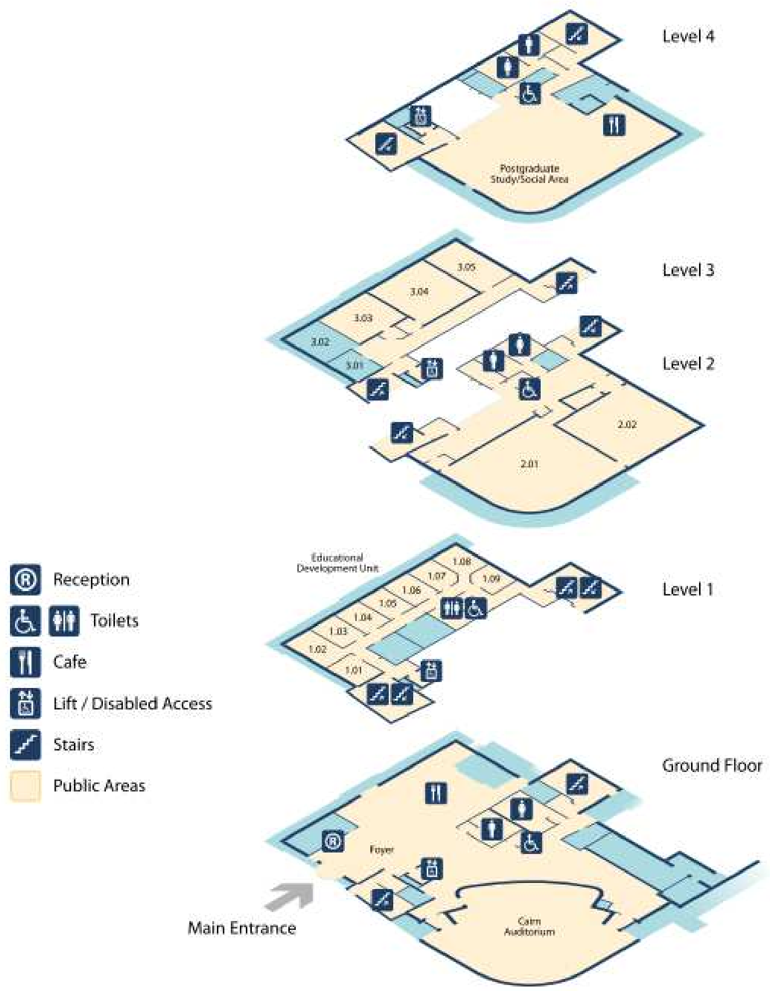

Figure 2 Post Graduate Centre Floor plan

The stepped roof in the study space on the top floor of the south zone allows natural light into the centre of the study area whist the perimeter full height glazing allows full advantage to be taken of the panoramic views to the north. Mechanically operated high-level louvres in the atrium assist in the natural ventilation of lower level areas under the stack effect. These arrangements are meant to provide a logical architectural solution and also allow the service and structural engineers' requirements to achieve the most economical solutions with regards to orientation and grouping to be best met [12].

Semi-structured interview

The qualitative data analysis involved a semi-structured interview with the building manager to shed light on the current issues pertaining to the PG centre and effective energy management. The interview consisted of questions mainly focussed on extracting insight as to how the building is operated, maintained and used on a day to basis. The idea was to identify areas where potential energy savings can be made.

Questionnaire

A questionnaire was designed and distributed in semester two to students and staff at the PG centre. For students a paper copy of the questionnaire was handed in by the authors before the class and collected after the class to ensure completion and return. For staff an electronic link to the questionnaire was provided. A total of 208 responses were received during the course of a week: this includes 81 post graduate (PG) students, 116 under graduate (UG) students, two academic staff and eleven support staff members.

Electrical Consumption data

Like most UK Universities, Heriot-Watt has also adopted a semester system which divides the academic year into three terms. The first semester is September to the end of November, the second semester is January to March and the third semester is April to June. The Estate Office, which is responsible for the energy management at HW University, provided the data on electricity consumption in the PG centre. This paper presents the analysis on the data for the second and third term to understand the electrical energy consumption patterns and their relationship with the activities that are undertaken within the building. The term dates for the year 2012/13 are as follows:

Term 1 (10/09/12 to 30/11/12)
Term 2 (07/01/13 to 22/03/13)
Term 3 (02/04/13 to 07/06/13)

Café information

Information is collected on the activities that occur in the café. The café opens from 08:00 to 15.30 from Monday to Friday and is serviced by two members of the catering staff. With the exception of the under-counter fridges 1 and 2 and another fridge and freezer which are constantly switched on, appliances such as the coffee machine, display fridge, electric till, soup kettle and turbofan oven run only from 08:00 to 15.30. This information is useful in understanding the base load of the building when not occupied. At the same time it is useful to know how the appliances, which stay on for the full duration of the café opening times, such as coffee machine, display fridge, electric till, soup kettle and oven, play a role in shaping the electrical consumption profile of the building.

Results

Semi-structured interview

The information obtained through the interview is given below and is purely based on the comments of the building manager.

The normal working hours for the PG centre are from 8am to 6.30pm from Monday to Friday. There is limited access until midnight on weekdays and from 8am to midnight on Saturday and Sunday. The building is alarmed and secured after midnight. The out of hours use of the building pertains mainly to the use of study space on the top floor or if there is an evening event.

A total number of 16 members of staff including the building manager, three academic staff and 12 support staff are based in the building. The routine working hours for most of the staff are from 9am to 5pm with access to lighting controls, a personal computer (PC) and shared network printers and photocopiers. There is a small kitchen on the first floor for staff containing a microwave oven, a dishwasher, a small fridge and an electric kettle. The dishwasher has never been used.

The building is both naturally and mechanically ventilated, where mechanical ventilation is controlled by the building management system operated by the university Estates department. There are three air handling units which control the ventilation rate in lecture theatre, the meeting/seminar rooms and the study space. There is no on/off function and no provision is available to locally override the flow rate. The automatic windows on the top floor study area are switched on all the time and have sensors to open or close automatically depending on external conditions of wind, weather, rain and temperature. These widows however, do not close properly and occasionally jam which has implications in terms of energy consumption. Increases in temperature over a certain threshold require windows to be closed as the chillers activate for air-conditioning.

The lecture/seminar rooms are fitted with audio-visual equipment and are used quite heavily during term time. This means that a lecturer may forget to switch all systems off completely after the last lecture of the day. PCs may be shut down but the control panel which shuts down the projectors could potentially be left on. This means that the projector bulb could potentially be left on all night resulting in energy consumption as well as bulb damage. Projector bulbs are also expensive to replace. A software program used throughout the whole University shuts down the systems (lights, projectors, PCs) in all the lecture rooms at midnight to prevent projectors being on throughout the night.

Staff did generally switch the lights off in the corridor if they were the last to leave but this is no longer the case. A female staff member complained that she nearly tripped over as she was the last one to leave the centre and the lights were off. The lights were switched off for energy efficiency purposes but posed a health and safety risk. The top floor lights are usually left on as students don’t tend to switch them off. Most of the time it is the cleaning staff who come in the morning at seven who switch them off. Students at the top floor also have access to a tall fridge, a microwave and a water chiller. The night lights are on timer and come on depending on the sunset times over winter and summer.

The stair case does get extremely hot in peak summer days due to glazing and seems deserted. There is no shading and the use of lifts increases as people avoid taking the stairs due to it being so hot. The teaching room on the 3rd floor has been found to be irritating as there are no windows to control temperature, so during the summer there is a high dependency on air-conditioning which is centrally controlled. People have windows open particularly on higher floors letting all this energy escape which is not only a waste but also distressing to staff that are feeling hot.

Questionnaire

To get an understanding of how the building is used by the occupants and how much impact this has on energy consumption, a questionnaire was distributed to staff and students at the PG centre. This section presents some of the results from this study. The results of the questionnaire indicated that 70% of the respondents fall within the 15-24 age band, 21% between 25-34, 7.5% between 35-44, 1.4 % between 45-54 and only 0.5% between 55-64. 68% males and 32% females completed the survey and include 39% post graduate (PG) students, 55% under graduate (UG) students, 1 % academic staff and 4% support staff. This indicates the major users of the building are PG and UG students where the staff based in the building constitutes a minor proportion.

The questionnaire results demonstrate that during term time two the major purpose for visiting the PG centre by students is to attend a lecture. This can be seen from Figure 3 which shows that around 90% of the respondents visit the PG centre to attend a lecture. Around 10% of the respondents visit to use the cafe and a similar proportion visit to use the study area on the top floor.

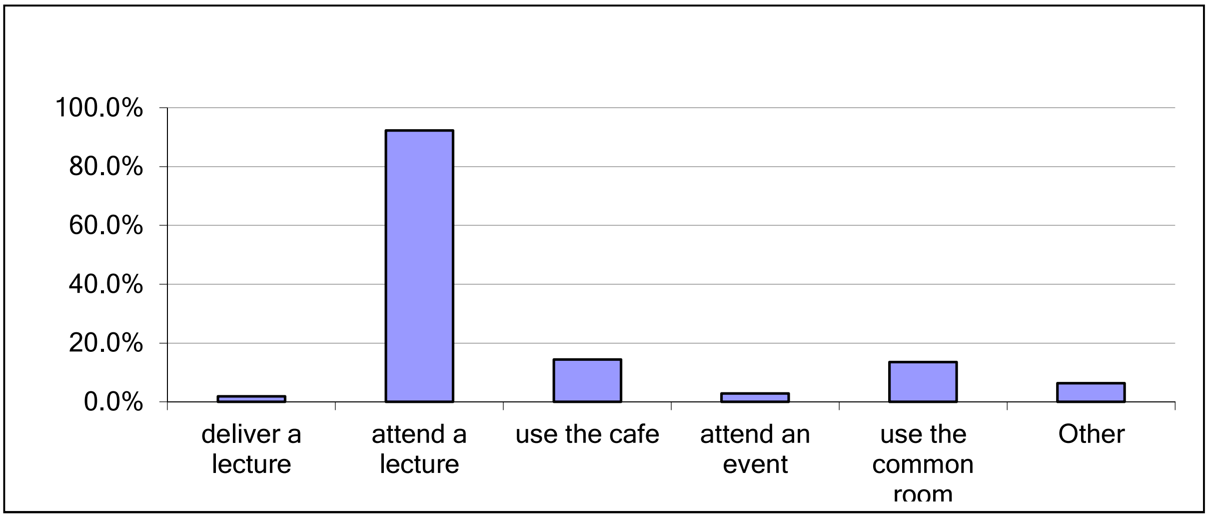

Figure 3 Reason for visiting the PG centre

The questionnaire results have shown that the average amount of time that most of the respondents spend on a daily basis at the PG centre is between one to four hours. This is understandable as most of the respondent visit the building to attend a lecture which is usually three hours long. A small number of respondents (predominantly staff) do spend between seven and nine hours daily at the PG centre.

Participants were asked about the equipment they use at the PG centre and the results are shown in Figure 4 below. The figure shows that 68% of the respondents use a laptop, 12% use a PC and similar proportions use a photocopier and a printer. Around 4% (this figure mainly pertains to staff) said that they use an electric kettle and table lamp. Between 12 to 28% of the respondents said that they also use their tablets/IPads at the centre. To be able to make a judgement on how this usage might influence the electrical consumption of the building, the participants were asked to rate their usage using ‘always’, ‘sometimes’, ‘rarely’ and ‘never’ responses.

Figure 5 shows that around 60% of the respondents never charge their mobile phones, laptops or tablets at the PG centre and therefore do not add on to the electrical consumption of the building. A negligible number of respondents say that they always charge their mobiles and laptops with around 20% respondents saying that they rarely charge their mobiles, laptops or tablets. Figure 5 shows that 32% of the respondents switch off lights when not in use whereas only 14% of the respondents say that they switch off their PC when not in use.

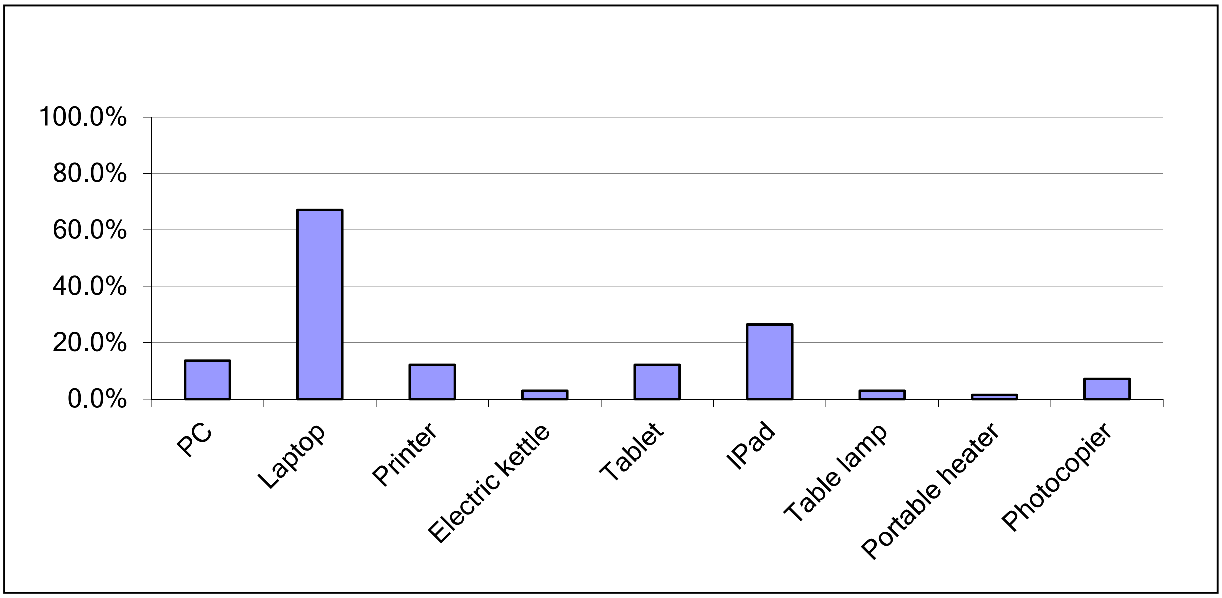

Figure 4 Use of electrical equipment at the PG centre

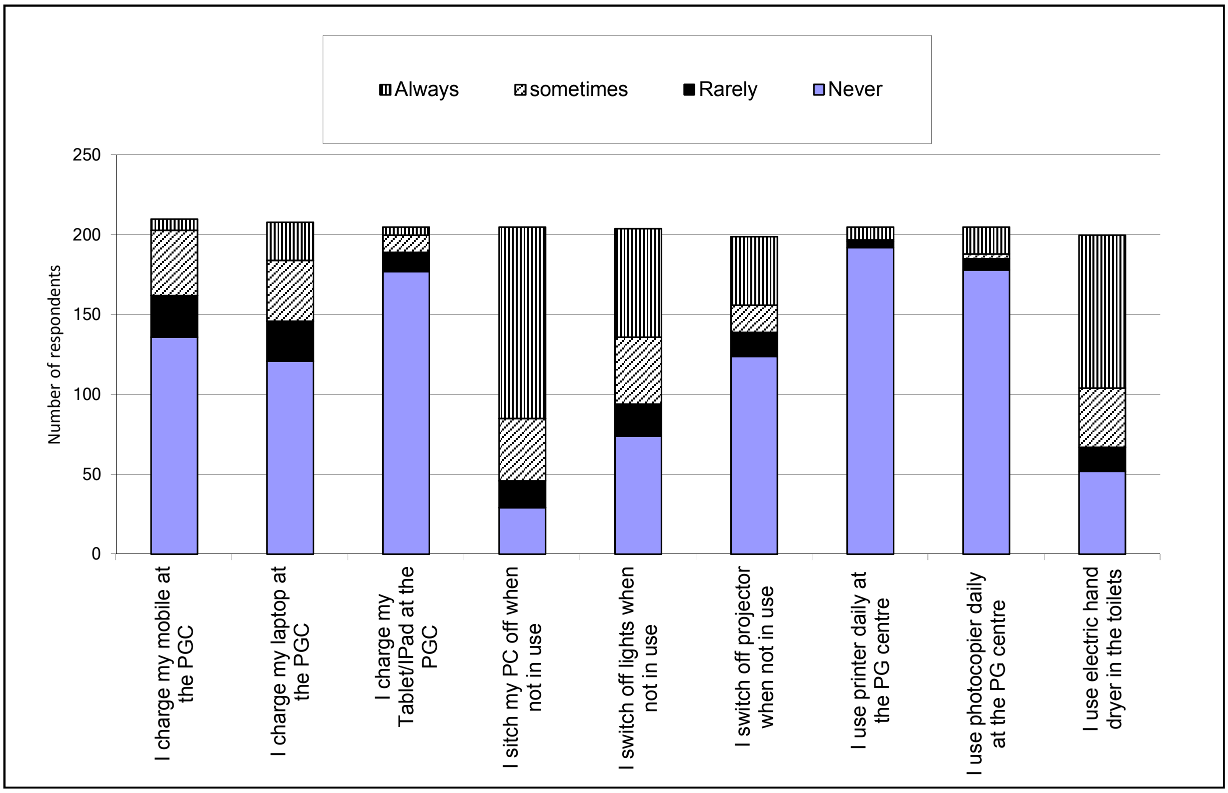

Figure 5 Rating of actions by the user

Average daily electrical consumption

This section briefly analyses the daily electric consumption of the case study building. Figure 6 presents the monthly average plots to demonstrate daily electricity consumption patters of the building during terms 2 and 3 (as specified in Section 2.3). This information helps to examine the trends of electrical consumption and their relationship with the activities that are undertaken within the building.

The analysis has been carried out at each half hour point of the day (starting from 00:00 to 23:30). Figure 6 has been complied in to four graphs to distinctly present electricity consumption patterns in a) January; b) February; c) April and d) May 2013. It should be noted that only weekdays in terms 2 and 3 have been used for the purpose of our analysis. This figure highlights that different months have very similar patterns of electrical consumption, with similar gradients in energy use at similar times.

On comparing average consumption between 08:30 to 19:30 across different months it can be clearly seen that there are considerably lower values in April and May than in January and February. This could be due to the effect of heavy usage of the building during term 2 when teaching activities are in

full swing in comparison to term 3 when most of the students are preparing for exams and may not be on campus. This is discussed in the following section below. This variation could also be due to weather related changes as the days get brighter and a bit warmer in April and May. This requires climate data information which is not in the scope for this paper. From figure 6 it is evident that the maximum electrical consumption occurs in January (58 KW) followed by February in term 2. In term 3, plots for April and May show a reduction in the range of 11 KW to 14 KW from the peak consumption in January. This may be attributed to a higher heating load in the winter season, whilst in May the heating is switched off centrally.

The plots in figure 6 follow a general trend where the demand profile exhibits a base load which starts rising at a certain point in the day (03.30) and continues to increase until the building opening hours (0700 hours), to its peak value (noon). The initial ramp could be the result of the switching on of electrical heating pumps and fans for the heating or cooling systems [14] as well as the electricity consumed by active appliances (e.g. lights, kettles, computers, printers, photocopiers, microwave ovens) and standby appliances (e.g. desk-top computers, display monitors and printers. The profile then slowly slopes back towards the base, and reaches the base load value after the building is closed (midnight). Drawing on the idea of Firth et al [13] the base consumption of the centre may include the electricity consumed by continuous appliances which have to remain switched on all the time e.g. security cameras, information displays and computer servers and cold appliances in the café such as refrigerators. The electricity consumed by active appliances (e.g. lights, kettles, computers, printers, photocopiers, microwave ovens) and standby appliances (e.g. desk-top computers, display monitors and printers) is flexible consumption, because these kinds of electric equipment and appliances can be switched on/off at any time, depending on the behaviour of users. The peak occurs in the afternoon followed by a gentle decrease from 19:00 onwards with further decrease from 21:30 when the out of hours access applies. It can be seen that during the month of January the maximum average load occurs at 58 KW and the minimum average load is around 24 KW.

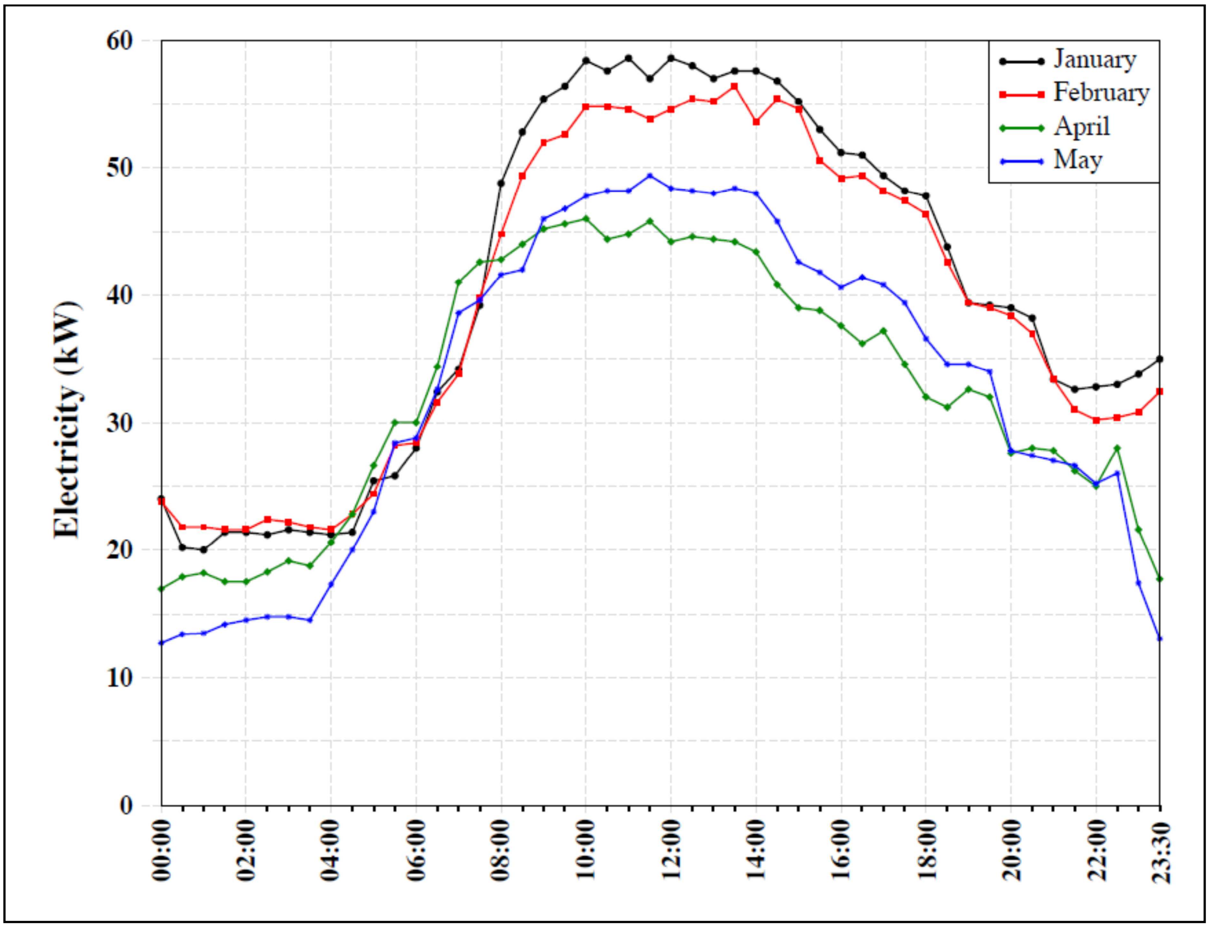

Figure 6 Average daily electrical demand profile of the PG centre a) January b) February c) April and d) May 2013

Room activities and daily electrical consumption

The main focus of this paper is to determine the influence of room activities in terms of lectures, seminars or meetings on the energy consumption of the building. Information was collected on the occupation status of all meeting/teaching rooms within the building from January 2013 to May 2013. At a glance, the average daily profiles provided in Figure 6 provide a good indication of how energy demand changes over a certain period of time. In order to understand the influence that certain activities have on the energy consumption it is better to perform the analysis on an individual day basis. For the present study, two typical days are selected from January and February when the term is at its peak, and two from April and May when most of the lecturing is finished. Figure 7 presents the results for these selected days where a, c, e and g present half hourly daily electrical consumption (KW) profiles for 11th Jan, 11th Feb, 11th April and 7th May respectively, and b, d, f and h show the room occupancy due to certain activities taking place in the lecture theatre, meeting/seminar rooms and café on those days. From the collected information it is noted that the main activity that occurred in the months of January and February was teaching (lectures) whereas in the months of April and May it was mostly meetings and social events. This is in line with the information obtained through the interview and the questionnaire which confirms that the major activity taking place within the building during term-time is lectures.

Figures 7 (b,d,f,h) shows the number of rooms that are occupied on selected days. It is presumed that the more rooms occupied the greater the electrical demand of the building. This would mean that increased activities are likely to influence the electrical consumption profile due to the usage of electrical appliances such as PCs, monitors, projectors, lighting and mechanical ventilation.

Figure 7 (a) shows the electrical consumption profile of the building for 11th January. At a glance it can be seen that the profile follows the trend exhibited by the average profile for January. This is understandable as most of the activities which consume electrical consumption within the building take place between the normal working hours. Figure 7 (b) shows the plot for the café and occupation of six rooms within the building for teaching or seminar purposes. The figure shows that from 09:30 to 11:30 hours, room occupancy is quite high (4-5 rooms + café) whereas from 12:00 to 17:30 the room occupancy is low (1-3 rooms + café), but there is not a significant drop in electrical consumption.

On 11^{th} February from 9:30 to 12:00 four rooms are occupied along with the operating café. From 12:00 to 13:00 only the café is active and from 14:30 to 16:00 occupation increases back to four rooms. It is however, interesting to note that there is no significant drop in electrical consumption from 12:00 to 16:00. It can also be seen that there is a random peak from 16:00 which seems to be independent of the occupancy status of the rooms (café closes at 15:30). From figure 7 (f) it can be seen that the occupancy rates are high most of the time but the profile in figure 7 (e) again follows the general trend irrespective of the occupancy. Figure 7 (h) demonstrates the least amount of room occupation corresponding to the fact that most students are away on exam leave in May. It is apparent from Figure 7 (g) that this decreased occupation has no impact on the consumption profile.

One would think that the ventilation systems are configured and controlled to enable the system to run at reduced flow rates during times of low occupancy or when the room is not being used. This implies that the automatic systems are still running irrespective of the fact that there are no occupants in the rooms and no activities are being carried out. From Figure 7c and 7d, it can be seen that other than the café, no other activities occur in the meeting rooms from 12 to 1 pm, but this does not have any impact on the electrical consumption of the building. The question arises as to why these activities do not match the electrical profile. In a non-domestic building in the UK around 19% of the total operational carbon emissions are from lighting, 16% for mechanical ventilation, 16% for office appliances whilst catering constitutes only 4%. This corresponds to an equivalent percentage of energy consumption [15].

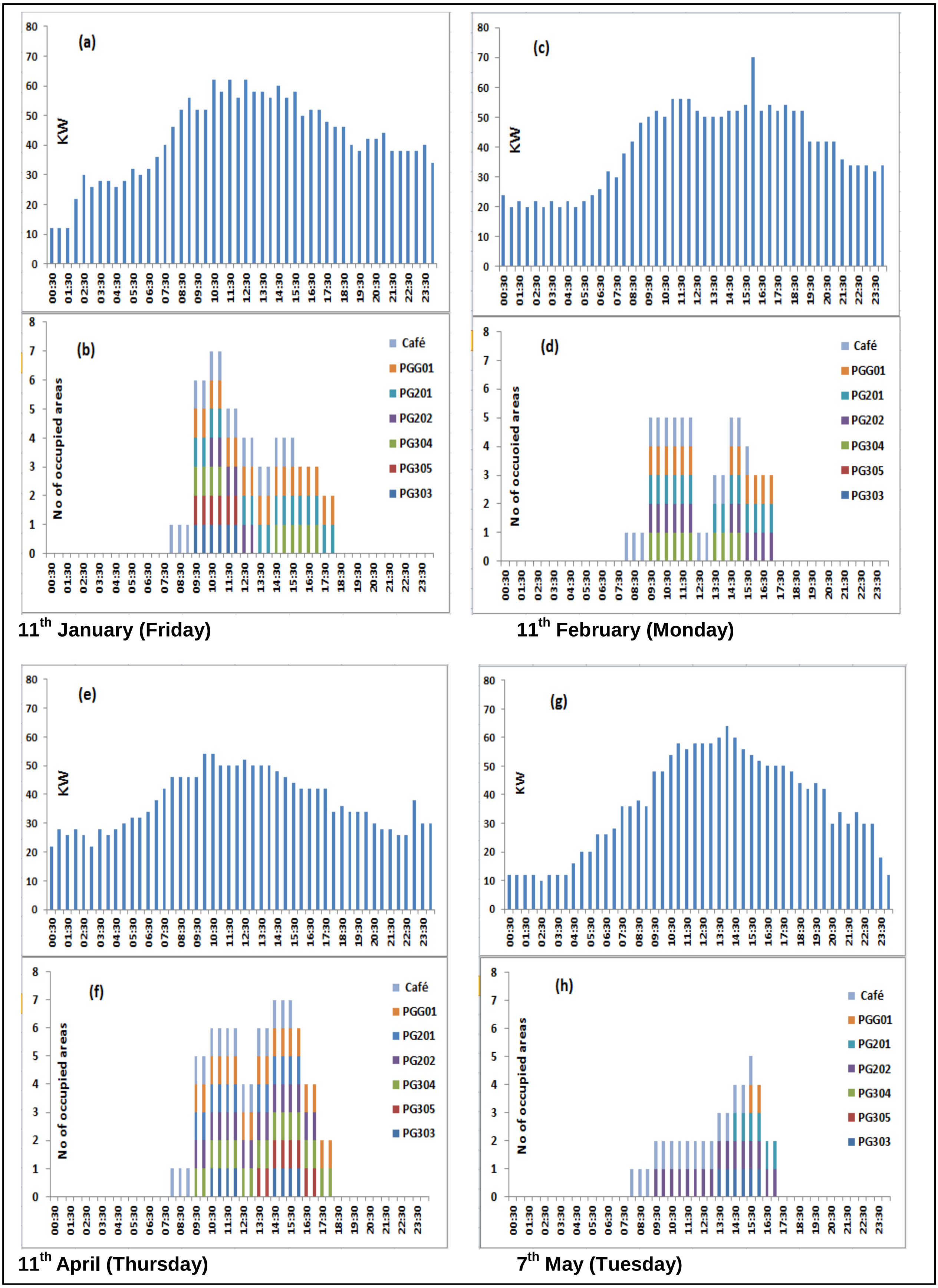

Figure 7 Electrical consumption (a, c, e, g) versus number of occupied areas (b,d,f,h)

Conclusions

Energy consumption in a non-domestic building is a very complex issue where energy demand profiles of a building are attributed to a variety of physical and behavioural factors. The modelled energy calculations do not take into account all the factors related to a particular building as a result of which the measured energy use is significantly higher than the estimated energy use. This empirical study is an attempt to understand the reasons responsible for this performance gap for a case study university building. A semi-structured interview was conducted with the building manager to understand the nature of the building operations and to identify the issues which have an impact on the energy efficiency of the building. A questionnaire was distributed to the building users (staff and student) to get an understanding of the building use. From the interviews and questionnaire it is apparent that the major use of the building is for teaching and non-teaching activities, where the non-teaching activities include the café, cleaning activities and staff using the office spaces. Most teaching activities occur in term 2 whereas it is meetings and events that take place in term 3 when most of the students are away for exam preparation.

This pilot study has indicated that the building users have a small influence over the electrical consumption of the building. During term time when the building is mostly used for teaching activities, students are the main users and tend to visit the building for the duration of their lectures. UG students do not seem to exhibit a responsibility towards switching off lights/projectors. Students however, may influence the consumption by increasing the use of services provided by the café. The catering activities however, constitute a small proportion of the total consumption of a non-domestic building. It has been highlighted that the heating/cooling systems of the meeting/seminar rooms, study space and lecture theatre are operated by a Building Management System (BMS) which is controlled by the university Estates department. The purpose of the BMS is to take control of these operations in the most efficient way possible within the constraints of the installed plant. The BMS is therefore a critical component in managing energy demand. Improperly configured BMS that are rigid tend to increase building energy usage.

This study has identified that the room occupancy has no significant effect on the electrical consumption of the building. In a building like the PG centre where all rooms will not be used throughout the day, the strategy for energy efficiency should be to configure systems such as mechanical ventilation to allow the ventilation to individual rooms to be reduced back to a minimum set-back rates when not in use. This will save energy in heating and cooling and will also significantly reduce fan power consumption. Since the building is automatically controlled by the BMS, the pre-set systems are not performing effectively to take into account the occupancy status of the rooms. What this study has unearthed would not have been identified from a normal energy audit. Identifying gaps in terms of day to day operation of the building certainly has the potential to reduce energy consumption along with installing energy efficient equipment.

This study reveals that a thorough and detailed investigation is required to get a better understanding of the effect of various factors and their complex interaction with the energy requirement of the building. The relationship between the energy demand profile and behavioural aspects of users as well as gathering operation data to get an understanding of the energy intensity of electrical appliances and systems with respect to floor area is required. Such information would help to develop a forecasting model based on the activities of a building at any certain time of the year. It is hoped that the applicability of this model would span to other buildings of similar type and can help energy/facility managers to plan optimum schedules for the automatic systems to achieve significant amount of energy savings.

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Achieving Premium Energy Performance in 2nd Tier Commercial Buildings

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Abstract

Existing premium grade office buildings in Australia have for some time now had the incentives and budget to upgrade engineering systems to high levels of efficiency. However, by contrast, 2nd tier office buildings have settled for very modest performance levels due to budget, returns and technology constraints.

In recent times, as building owners of 2nd tier commercial offices have realised the increasing differences in property values/ rental returns compared to premium properties, they have started to upgrade for energy efficiency. However, generally the original installed systems in these properties are not of a high standard and one-for-one replacement equipment has poor efficiency. Additionally, the original systems are often highly dispersed with only rudimentary levels of control available.

These obstacles need to be overcome, often with very limited budgets in occupied buildings, eliminating the opportunity to install a leading technology solution.

This paper presents a case study of a 2nd tier office upgrade project where an optimised suite of improvement measures within significant budgetary and technological constraints has resulted in exemplary efficiency performance.

The combination of careful plant selection, extensive controls refinement, intense commissioning and tuning carried out in a structured manner has allowed these projects to achieve these outstanding results.

This paper describes the approach taken during the design development and the commissioning and tuning processes to achieve/maintain the target energy performance outcome (4.5 Stars NABERS Base Building – approximately 70-75kg/CO_{2e}/m^2/year) after 12 months of occupation and operation. We have assessed the procedures and steps taken against the BSIRA Soft landings guidelines and core principles.

Introduction and background

87 Marsden St located in Parramatta, Sydney is a 2nd tier 6,660m^2 (7 storey) commercial office building. The HVAC system consists of decentralised water cooled packaged units (WCPU) on each floor serviced by roof top cooling towers. On-floor conditions are maintained by VAV units fitted with electric duct heaters.

Prior to the upgrade, the building was performing at 1.28 Stars NABERS Energy (Base Building). This is well below the average performance of office buildings in Australia which have an average rating of 2.5 Stars. The major tenant is a NSW government agency that insists on only occupying a building with a rating of at least 4.5 stars NABERS Energy (Base Building) requiring therefore an improvement of approximately 3.3 Stars. (A 56% energy reduction, approximately 800,000kWh/pa reduction)

In December 2013, the upgrade project of 87 Marsden St won the Australian Energy Efficiency Council's national award for the "Best Commercial Building Energy Efficiency Project" for its significant energy reduction and leadership in demonstrating market change potential.

Figure 1: 87 Marsden St, Sydney – SW elevation

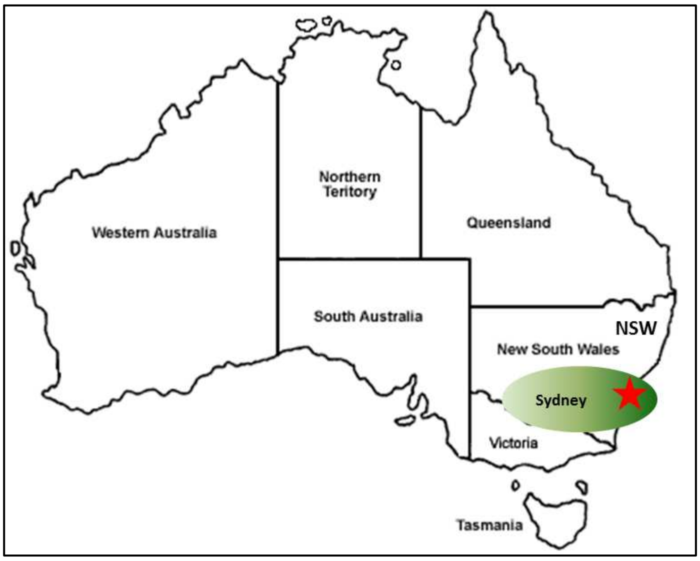


Figure 2: 87 Marsden St, Parramatta, Sydney – Location in NSW, Australia

Quintessential Equities, (the owners of 87 Marsden St) is an Australian property developer and fund manager that upgrades poorly performing properties in such a way that with improved performance and aesthetics they can be fully tenanted with long term tenants, substantially improving the value of the building.

Quintessential Equities have a genuine commitment to sustainability and are well informed of the issues. The project is not about simply ‘looking good’, but rather about delivering verified and measurable improvement, equal to or better than market benchmarks. The client is alert to 'greenwash' and is averse to compromising building performance. This unyielding commitment had significant impact on the design, construction and tuning processes.

Catalyst for change – Upgrading 2nd Tier Office Buildings

While there are now numerous examples of Premium and Grade A[1] office buildings across the capital cities of Australia that are performing at 4.5Stars NABERS or better, there are every few 2^{nd} Tier (Grade B or C) office buildings that perform better than the 2.5 Star average benchmark.

Buildings of this size and grade are in abundance in both outer metropolitan areas and regional centres. Generally the original installed systems in these properties are not of a high standard and one-for-one replacement equipment has poor efficiency. Additionally, the original systems are often highly dispersed with only rudimentary levels of control available.

Due to market and financial considerations, as well as the perception by owners that they need to centralise the HVAC services in order to achieve significant energy savings, very few of these buildings undergo major energy upgrade works.

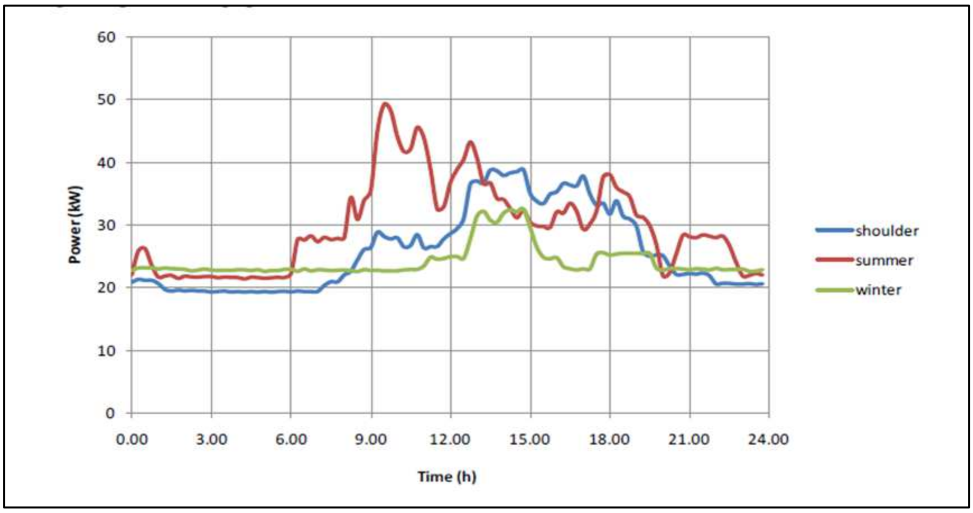
In addition to the site specific constraints, there is a real issue in regional centres across Australia in regards to adopting new and innovative technologies due to the capabilities of local tradespeople to service new systems. This project, through the reuse and optimisation of existing systems and technologies demonstrates that significant energy savings can be achieved in 2nd tier (PCA Grade B and C) buildings through careful plant selections and controls optimisation in regions that are starved of technical expertise.

Savings measures identification and Design Process

During August to October 2011 a thorough energy and water audit was carried out on site to identify energy end uses and opportunities for energy savings. This audit and subsequent report was carried out and prepared in accordance with the Level 2 Australian Standard for energy audits. (AS3598:2000) This is an investment level audit.

The audit identified a range of improvement measures with paybacks ranging from 2 – 8years, with some additional long term measures such as a PV array to be considered circumstances required energy generation to achieve the desired performance target.

Issues leading to excessive energy consumption included, after-hours operation of base building mechanical plant well beyond those required amounting to approximately 12% of the annual energy consumption. (See Figure 3)



[1] Property Council of Australia office grading system. www.propertyoz.com.au/library/Guide%20to%20Office%20Building%20Quality%20-%20Consultation.pdf

Figure 3: Weekend consumption profile – continuous base load and daily operation though all seasons

The End Use Breakdown (EUB) developed through the audit process identified the primary end uses of energy and allowed the team to focus on the large energy users. (Figure 4)

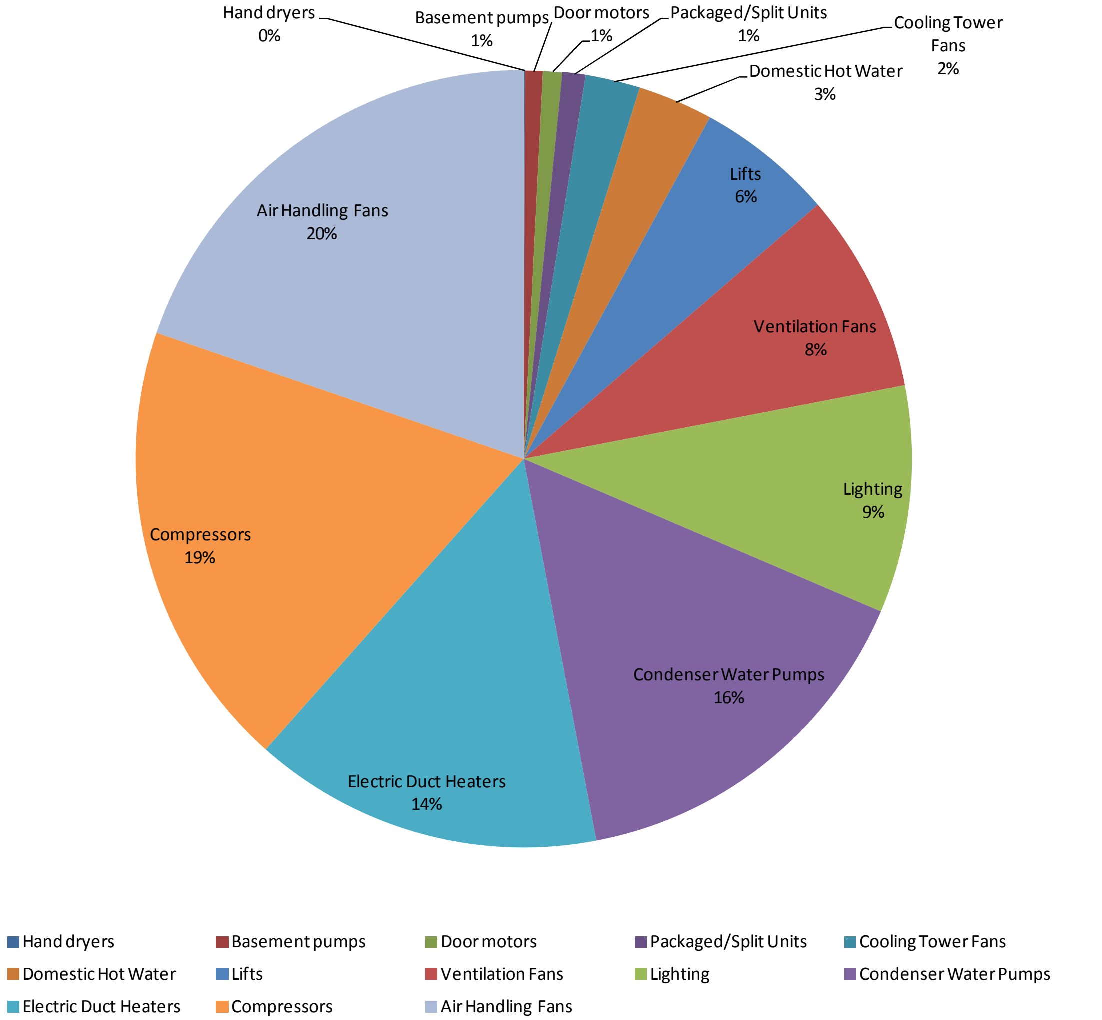


Figure 4: End Use Breakdown of all energy consumption

It is clear from the pie chart above that the electric duct heaters condenser water pumps were responsible for a significant proportion of consumption, through their lack of control, inability to "turn down" and long hours of operation.

The audit team carried out detailed analysis of each end use to identify operational and control issues, as well as excessive consumption as a result of unwanted operation.

The list of recommended measures identified included:

- One for one replacement of all on-floor water cooled package units (WCPU)
- Implementation of an economy cycle on 5 of the 7 floors
- Replacement of the base building and tenant cooling towers (end of life replacement)
- Reconfiguration of condenser water pumping, including installation of Variable Speed Drive controllers (VSDs) on all pumps
- Installation of a centralised Building management System (BMS) and development of optimised Functional controls

- A full re-commissioning of all air and water mechanical systems, including a complete rebalance and a rigorous tuning process post-completion
- Installation of energy and water meters and reporting system
- Replacement of base building lighting (car park, fire stairs, corridors and foyers) and improved controls
- Replacement of 2 electric Domestic Hot Water unit (DHW) system with a single heat pump

Prior to commencing the detailed design, a value management Study was carried out with the owners to ensure that all recommended measures would provide value and be aligned with the Quintessential's project objectives.

For this project a slightly different procurement method was used. Instead of engaging conventional design engineers, based on experience on prior retrofit projects, we engaged a mechanical contractor that was capable of doing design development. This allowed the client to put the onus on the contractor to be fully aware of all site conditions, all aspects of the design and therefore be able to sign up to a Guaranteed Maximum Price contract.

Under the model used, the energy/ESD consultant still held the responsibility to review and approve the design, as well as then acting as client side project manager and commissioning agent. This meant that the quality of the outcomes was not compromised and the Contractor took on all the price risk of the project.

Implementation and commissioning

Implementation of the project occurred from July 20012 to the end of December 2012. During this time the building was fully occupied with tenants, requiring weekly and in some cases daily communications.

Experience has shown that while many energy upgrade projects typically have minimal problems in the implementation phase, (contractors have all the necessary capabilities to install equipment) the energy performance targets are often not achieved as a result of poor commissioning and failure to correctly program and deploy optimised controls. BMS contractors often reuse control logic "code" from earlier projects, which is unsuited to the particular circumstances and specifics of each site and controls configuration. To avoid this issue, the consultant developed the Functional Description in conjunction with the BMS contractor and reviewed the control logic code at the time of deployment.

To ensure that the commissioning process was effective, a detailed commissioning plan and work method statements were compiled together with the contractor to ensure that process and testing methods were robust and verifiable. To minimise disruption to tenants, commissioning and witness testing of Variable Air Volume boxes (VAV's) was progressively carried out at night. This also reduced the likelihood of the need to retest on completion, had any problems only been found at completion.

As a further step to minimise tenant disruption and operations, all preparation works were completed in a way that allowed for the change out of 5 Package Units and 2 cooling towers to occur on a single day over a weekend. All tenanted areas had air conditioning operating again before work on the Monday morning.

Careful planning and coordination between all stakeholders led to a fantastic result where the project was completed on time and slightly below budget/Contract value, with only minor complaints from tenants over the 5 month construction period.

Operational reviews and tuning

During the 12 month Defects Liability Period (DLP) and tuning period, the team carried out 4 quarterly operational reviews of HVAC operation as well as 12 monthly energy reports. This was in addition to the regular scheduled maintenance for the new equipment.

The high number of reviews and combined efforts to address all issues as soon as possible had a significant impact on the final result and achievement of the target energy performance.

The quarterly operational review analysed the operation of all major pieces of HVAC equipment against the optimised control strategy. Specifically the following controls were investigated:

- VAV - achievement of flow set points
- VAV - control of VAV airflows
- AHU/ Package Units – Supply Air fan speed and VSD controls
- AHU/ Package Units – temperature set points
- Condenser water – pumping controls
- Sensors – all temperature and pressure sensors verified

A few example graphs are shown below:

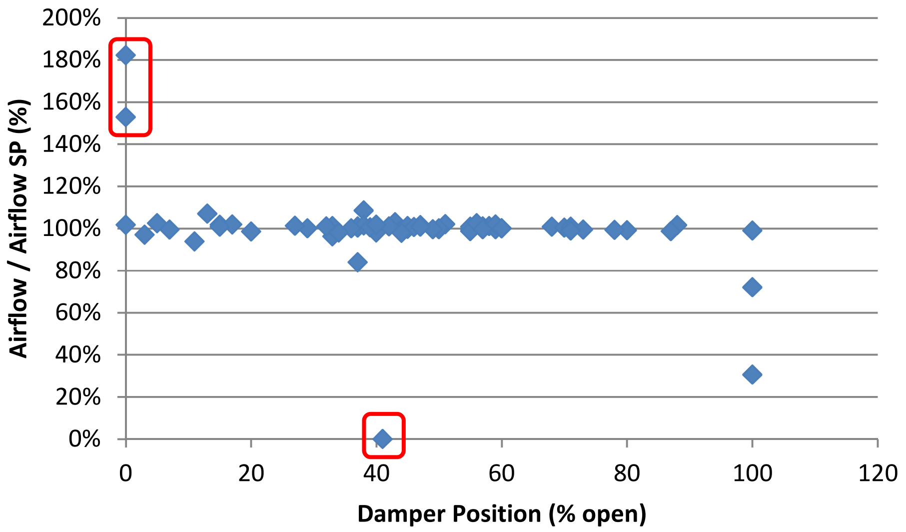


Figure 5: Majority of VAV boxes achieving their flow set-points – outliers highlighted in red.

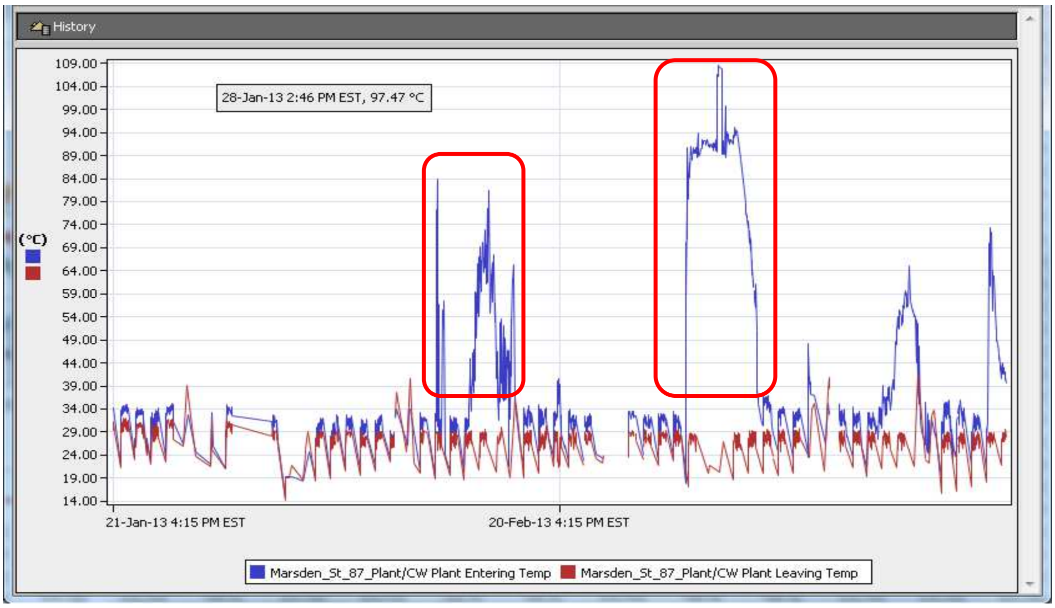


Figure 6: Unpredictable/inaccurate readings from Condenser Water temp sensor

Monthly energy reports investigated the energy consumption of all end uses against predetermined targets. This process allowed the team to identify incorrect operations through excess energy use, and also confirm if systems have operated in line with control strategies.

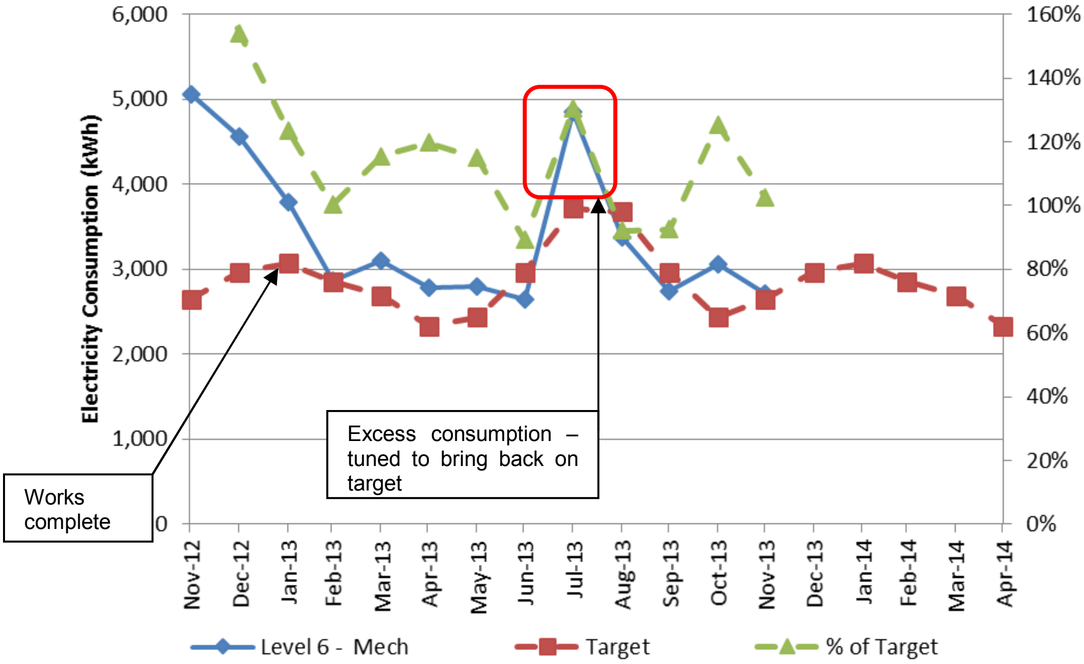


Figure 7: 12 month tracking. Highlighting times of excess energy consumption

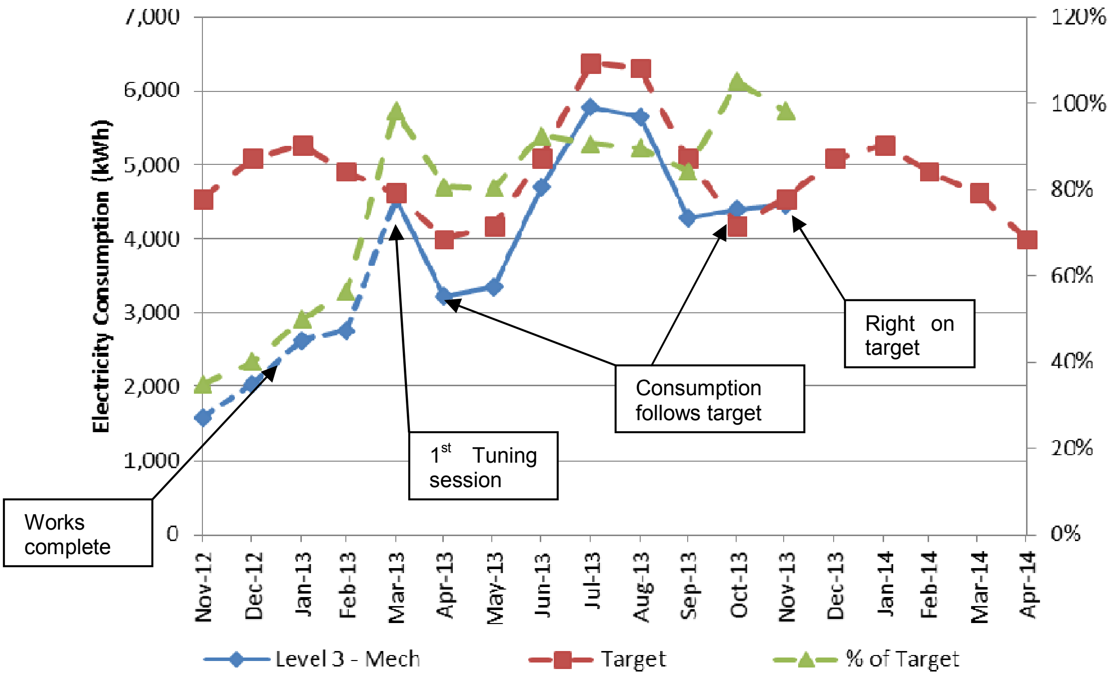


Figure 8: 12 month tracking of energy for the WCPU on level 3

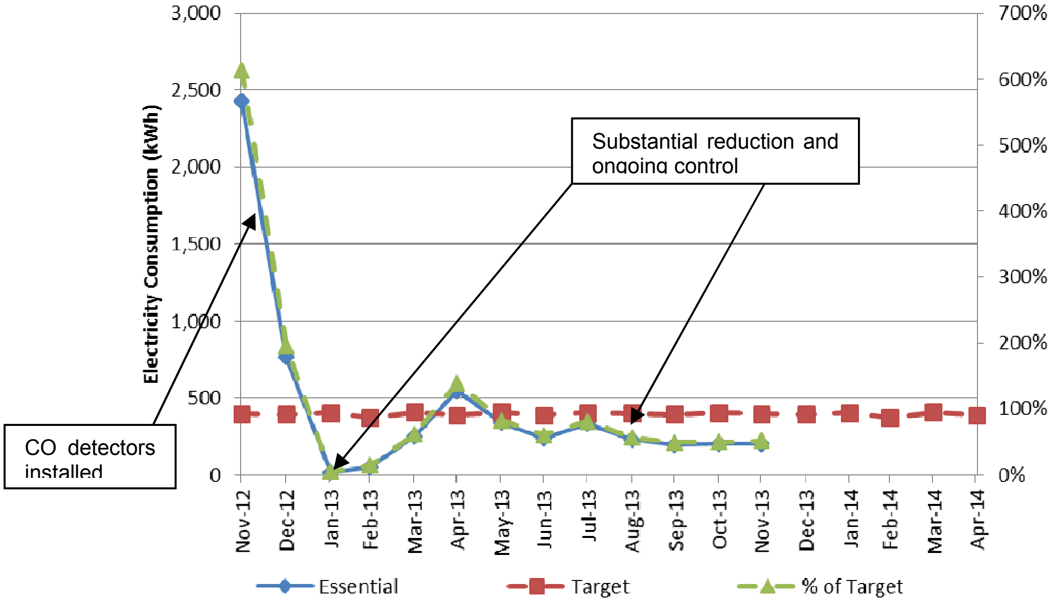


Figure 9: 12 month tracking of Carpark exhaust fan – operating on CO control

Project Outcomes

In November 2013, less than 12 months after completion of the works on site, 87 Marsden St was officially certified to be performing at the 4.5 Star NABERS Energy (Base Building)

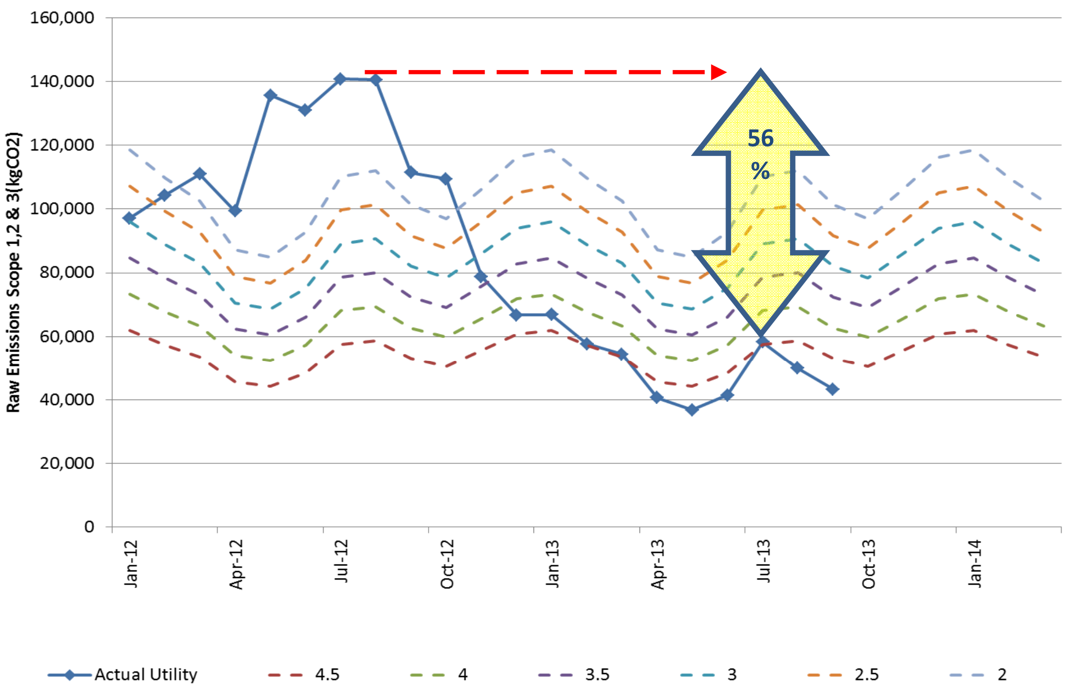


Figure 10: Overall building performance – plotted against NABERS rating profile lines (year on year reduction of 56% shown)

In December 2013, the upgrade project of 87 Marsden St won the Australian Energy Efficiency Council's national award for the "Best Commercial Building Energy Efficiency Project" for its significant energy reduction and leadership in demonstrating market change potential.

Evaluation of process under Soft Landings framework and core principles

In 2001-12, Building Services Research and Information Association (BSIRA) and the Usable Buildings Trust (UK) launched the Soft Landings program. The intent of the program is to extend the length and depth of involvement that the designers and constructors to help ensure performance targets are achieved and ensure the occupiers understand how to control and best use their buildings.

The Soft landings program comprises 12 core principles that should be adopted through all stages of the project. In line with recommendations from BSRIA, the Soft Landings principles were not used as contractual requirements, but rather used to inform and guide the project delivery pathway.

This project was carried out from the outset as a Soft Landings project, which definitely assisted in a smooth and informed handover/transition.

The purpose of this evaluation is not to prove or disprove the Soft Landings framework, but rather to test which elements were demonstrated to be most beneficial.

Table 1: Evaluation against Soft Landings framework and principles

Item	Framework and core principle	Applied Yes/No	Effectiveness
1	Adopt the entire Soft Landings process from commencement. Be explicit in implementation through all 5 stages	Yes	Our observation is that it is <u>essential</u> to be brought in to play <u>before commissioning planning</u> begins. By adopting the Soft landings principles from early on definitely made commissioning a smoother process and had better acceptance.
2	Provide leadership and have champions for Client and Contractor. Engender trust and open/honest collaboration	Yes	Clear <u>leadership definitely helped</u> the team embrace and focus on performance outcomes. Leadership was provided by the energy consultant that acted as project manager and commissioning and tuning agent. All parties had a <u>“no blame”</u> attitude and <u>“pulled together”</u> to make sure it all worked correctly and efficiently.
3	Set roles and responsibilities for all stages and ensure continuity. Active participation of client/owner and occupant representative	Yes	Role definitions were clear from the start. Leadership was established early on and accepted by the team, keeping the focus on outcomes. The same leadership continued through into the post-handover stage and is still making sure tuning activities are correctly identified and implemented. <u>Continuity of performance intent is essential from construction to occupation and operations</u>
4	Ensure continuity of Soft Landings thread throughout the entire project	Yes	As noted above, a <u>successful outcome</u> has been achieved. Our observations would confirm the importance of nominating a single person to be responsible for carrying the <u>continuity of intent through from one stage to the next.</u>

Item	Framework and core principle	Applied Yes/No	Effectiveness
5	Commitment to post Practical Completion "aftercare" for 3 years with continuous feedback in place	Partial	Both the Contractor and Owner have committed to post-completion tuning and monitoring "aftercare". This has proven to be critical to the achievement of the target performance. However, only for 12 months Having a structured and planned tuning process and regular measurement/reporting of energy use against targets has ensured that remedial actions were carried out in a timely manner, allowing for earliest possible rating of performance
6	Share risk and responsibility in a collaborative "no blame" approach	Yes	Since there was no contractual obligation for the construction team to achieve the performance outcomes, sharing of risk was practiced. This "no blame" mind-set definitely contributed to the willingness of parties to contribute and collaborate.
7	Use feedback and surveys to inform design	Yes	Feedback and contribution of ideas and experience from previous projects had a big role to play in the success of this project. Lessons learnt by the commissioning and tuning teams have already been brought to bear on performance improvement and on other recent projects. Building Manager and occupant observations and feedback have had significant input into the resolution of issues and identification of energy efficiency opportunities
8	Focus on operational outcomes in-use and refine targets	Yes	The continuous focus and attention to in-use performance outcomes has unquestionably contributed to the success of the outcomes to date. Regular tracking and monitoring of energy use against targets has been essential in maintaining focus. Targets were reviewed and refined after the first 6 months of operation

Item	Framework and core principle	Applied Yes/No	Effectiveness
9	Involvement of Building Manager and maintenance crew	Yes	Early involvement of the Building manager and maintenance crews, through the commissioning and tuning processes provided substantial value to the process.
10	Involve end-users in all stages of the project	Partial	Early involvement ensured that the building manager was able to operate the building efficiently in record time. As noted, direct feedback from occupants, has been helpful in the identification of efficiency opportunities in the work spaces
11	Set realistic performance objectives	Yes	In Australia, the NABERS rating scheme provides a realistic industry benchmark. This allows for the identification of achievable performance goals. NABERS covers energy (emissions), water and waste – for the base building services and for tenancy spaces. All monitoring and measurement is carried out following strict protocols against these standard benchmarks.
12	Communication and information sharing between all parties over each stage	Yes	Regular and open communication in terms of expected outcomes and required activities played a major part in the finalisation of the commissioning and handover processes. During the latter part of the12 months of “aftercare” to date, communication has continued and performance levels are being maintained.

Conclusions

This paper contains two sets of conclusions:

1. The conclusions and lessons from the approach and processes undertaken during design, installation and commissioning, and

2. The conclusions in relation to the application of the Soft landings process

This project has clearly demonstrated that there is an economically responsible solution for 2nd Tier commercial office buildings to achieve “Premium Grade” energy performance levels.

Instead of using a capital and new technology intensive recipe, owners and building managers have the option, with careful design considerations and well-structured installation and commissioning processes, to re-invigorate their 2nd tier buildings and reposition them in the market. A core ingredient in this low cost recipe is the continual focus by the project manager through all stages and hand-overs on the final energy outcome. This continuity of intent, from the original concepts and discussion of client objectives, through each “change of hands” of the project’s life, is critical to ensure that different stakeholders (designers, installers, commissioning technicians or building manager) as they take control of the project, are aware and focussed on ensuring the defined outcomes are considered and verified every step of the way.

Other key lessons to note are:

- All energy conservation measures should be reviewed with the client through the course of a value management study, where clients are exposed to the full scope details, budgets, savings and associated risks, before the final selection of scope is made. In other words, avoid allowing clients to select measures based on purely “payback”, but rather take into account all aspects

- It is worth considering, especially on retrofit projects, the option of engaging contractors that have engineering design capabilities instead of independent design engineers. This can minimise claims for variations, latent defects and delays and ensure that the contractor remains accountable for the outcome

- Provision of a concept Functional Description as the starting point of the full Functional Description is very useful to ensure that the BMS Controls contractor is not tempted to simply adopt a previous FD template that is unsuitable for the project and also ensures that the designer and Controls contractor are heavily engaged defining the controls and forced to review each other’s work

- Successful tuning of systems requires explicit separation of the optimisation and tuning steps versus the defect rectification process. Defect rectification for contractors is largely about “closing out” works and walking away, while correctly structured tuning requires constructive review and improvement. Having these 2 processes carried out by different resources forces this separation and results in win-win situation as Contractors do not then feel they are simply having more and more scope added, for no return

In line with expectations of the Soft landings program, attention, leadership and effort during the design, construction and tuning stages has delivered a performance outcome that exceeds industry experiences and timelines.

Application of the majority of the Soft Landings core principles and some additional procedures (procurement model) has demonstrated that industry best practice outcomes can be achieved in a timely manner without compromising operational function and thermal comfort.

While this project did not explicitly follow the Soft Landings framework, it has confirmed that the core principles carry substantial benefit when applied diligently and there are potentially a few additional practices that could be adopted into the framework. These include:

- clearer planning requirements for the tuning process
- explicitly defining the Soft Landings lead role that is continuous through-out all stages
- better defining active independent verification of commissioning execution
- defining the scope and how to procure services post 12 months DLP
- defining the need for post-occupancy training and coaching for occupants and maintainers

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Energy efficiency analysis of a flagship green building

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Abstract

Council House 2 (CH2) is a commercial building located in the Central Business District of Melbourne, Australia. The building was constructed in 2006 and was designed as a low energy building, purpose built for its owner and occupier, the City of Melbourne council. The building showcases a number of innovative technologies and is touted as the City's 'Sustainability Flagship'. However, the actual energy performance of the building had not been formally critiqued prior to the study that is the subject of this paper. The study revealed the building was performing well below its potential and the project's key findings serve to illustrate some of the challenges with respect to achieving high performance in advanced buildings.

The building's various features include passive chilled beam cooling, tri-generation, thermal storage phase change material, shower towers, building-integrated wind, solar PV and more. The key issues identified by the study as preventing high level energy performance were almost exclusively focused on the commissioning and control strategies applied to these systems not only in isolation, but in the complex web in which they come together.

This paper summarises the background analysis that led to discovery of the key issues and details examples of opportunities relating to flawed control strategies and control behaviour, concluding that the building is an excellent illustration of the importance of optimising control strategies and commissioning control behaviour for sub-systems not only individually but also in their operation as a whole system under numerous scenarios.

1. Introduction

Officially opened in August 2006, CH2 was Australia's first "6 Star Green Star – Design" building and showcases a number of sustainable building features. The building was designed to set new standards for low energy and high occupant comfort, bringing together a range of innovative technologies not only for the benefit of those to work in it, but also to serve as a sounding board for the broader industry.

But how does the building actually perform? With doubt that the building was achieving its ambitious targets, the authors of this paper were invited by the City of Melbourne to undertake a review of the building's energy efficiency performance in July 2012, providing an opportunity to review the performance of the innovative and experimental design features of the building.

The aims of the project were to:

- Quantify the existing performance of the building against National Australian Built Environment Rating Scheme (NABERS) Energy benchmarks
- Identify issues impeding energy efficiency performance
- Detail measures to improve the energy efficiency performance
- Identify lessons that can be learnt from CH2

The review was based on the findings of a whole building level 2 energy audit conducted by Dr Paul Bannister, Matthew Hoogland and Ben Carmichael as per the requirements of AS/NZS 3598:2000.

Note that the scope of the review was predominantly targeted at identifying energy efficiency measures to improve the NABERS Energy performance of the building. We acknowledge that there are numerous features of interest within the building however in general, our investigation only went as far as that required to improve the efficiency of the core systems making a significant impact on the building's consumption. As such, detailed investigation of the peripheral features of the building such as renewable power sources and automated shading systems were not covered. We also note that water efficiency and Indoor Environment Quality were not included in the scope of the review.

Figure 1: CH2 west facing façade (source: [1])

2. Building features

The features of CH2 that were intended to contribute to high level energy performance are listed below. Note that we have divided the features according to the significance with which we observed them having to the building's current performance:

- Core features:
    - Passive chilled beam cooling
    - Tri-generation
    - Hydronic radiant heating
    - Extensive heat transfer and recovery between water loops
    - Phase change material tanks for thermal storage
- Peripheral features:
    - Building integrated wind power
    - Solar PV and domestic hot water
    - Shower towers
    - Electronically actuated windows and shading

- Daylight harvesting

At the time of CH2's construction most of these technologies were far from common within Australia's commercial building industry and whilst chilled beam technology and tri-generation systems have since become more widespread, features such as the shower towers and phase change storage tanks are still relatively uncommon amongst Australia's commercial building stock.

Of the building's array of technologies, arguably most technically significant is the extensive potential for heat transfer between the seven distinct water loops. A simplified water schematic of the site's servicing is presented Figure 2. Among others, heat exchangers can be observed between the domestic hot water system and the primary heating water system, the primary heating water system and the primary condenser water system, the primary condenser water system and the supplementary condenser water system and the supplementary condenser water system and the primary heating water system. While none of these processes in isolation are particularly unusual, their summation equates to a system of unusual potential and complexity.

The complexity of CH2's design, coupled with the industry's general lack of familiarity with its features has proven to be one of the key challenges for the building's operation.

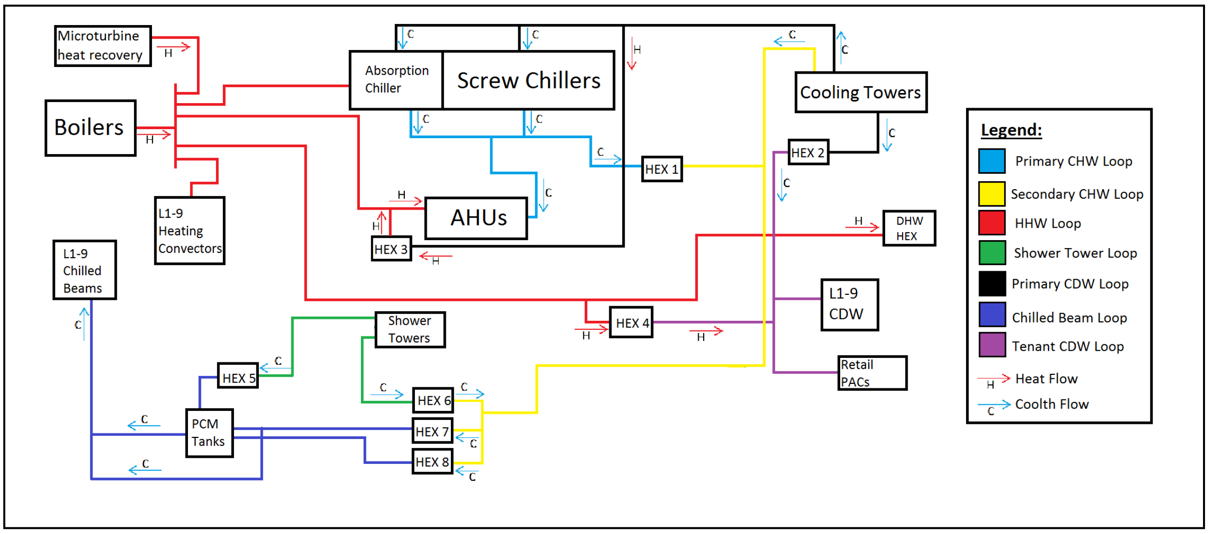

Figure 2: Simplified water schematic of HVAC services for CH2, demonstrating the diverse array of water loops and the heat transfer potential between them. Note that each line represents a flow and return path. See HEX legend in Table 1.

Table 1: Heat exchanger (HEX) legend corresponding to Figure 2

HEX Unit	Description
HEX-1	HEX to transfer coolth from the primary CHW to secondary CHW
HEX-2	HEX for transfer between the cooling towers and the supplementary CDW system
HEX-3	HEX for heat recovery from the primary CDW return to airside heating
HEX-4	HEX for heat injection into the supplementary CDW system (for reverse cycle PACs)
HEX-5	HEX for transfer of coolth from the shower towers to the chilled beam network
HEX-6	HEX for transfer of coolth to pre-cool the secondary CHW return after its path through HEX-7 and/or HEX-8

HEX-7	HEX for transfer of coolth from the secondary CHW system to either of the chilled beam network directly or via the PCM tanks (parallel to HEX-8)
HEX-8	HEX for transfer of coolth from the secondary CHW system to either of the chilled beam network directly or via the PCM tanks (parallel to HEX-7)

3. Current energy performance

3.1. Background to the NABERS Energy rating scheme

Our analysis benchmarked the building against the National Australian Built Environment Rating Scheme (NABERS). The NABERS Energy rating is a 1 to 6 star rating that normalizes the rated property's equivalent greenhouse emissions over a 12 month period against parameters such as building size, occupancy and climate. The NABERS administration advises that 5 stars is considered "excellent performance" whilst 6 stars is "market leading performance" (www.nabers.gov.au).

For office buildings, a NABERS rating can be assessed for the "tenancy", "base building" or "whole building". A "tenancy" rating is a performance assessment of the typical tenant services such as office equipment and office lighting. The "base building" rating assesses the typical landlord services, for example air-conditioning, lifts and back-of-house lighting. The "whole building" rating is a combination of the two.

3.2. NABERS Energy performance of CH2

CH2's energy performance is currently not meeting the high standard of its design. Our analysis revealed the Whole Building NABERS Energy performance of the building to be 4.08 stars ("good performance"). With the aid of data obtained from the floor-by-floor sub-metering system we were able to drill down to investigate the weighting of the base building and tenancy on the whole building rating. Our analysis found the base building to be performing at 3.24 stars NABERS. With several major property owners in Australia now reporting average portfolio ratings of 4.5 stars or higher ([2], [3], [4]), this is well below the current industry standard for high performance. At 3.24 stars, the emissions attributable to CH2's base building services are 68% greater than what they would be if the base building was performing at 4.5 stars.

NABERS performance parameters for each of the tenancy, base building and whole building are presented in Table 2.

Table 2: NABERS Energy performance parameters for July 2011 to June 2012

	Whole building NABERS rating	Estimated base building NABERS rating	Estimated tenancy NABERS rating
Date range	1/7/11 to 30/6/12	1/7/11 to 30/6/12	1/7/11 to 30/6/12
Electricity (kWh)	971,270	571,292	399,978
Gas (MJ)	5,133,122	5,133,122	0
Diesel (Litres)	0	0	0
Net lettable area (m^2)	7,200	7,200	7,200
Hours of occupancy	49.2	49.2	49.2
No. of computers	454	n/a	454
NABERS rating (decimal)	4.08	3.24	5.43
NABERS star rating	**4.0 stars**	**3.0 stars**	**5.0 stars**

4. Energy consumption analysis

Interval data was obtained for the office building's sole electrical utility meter. The analysis revealed unusual variation in the base load over weekdays and seasons, as presented in Figure 3.

With minimal occupation of the building outside of business hours, these observations were tell-tale signs that there may have been frequent HVAC operation occuring outside of the operational hours of the building.

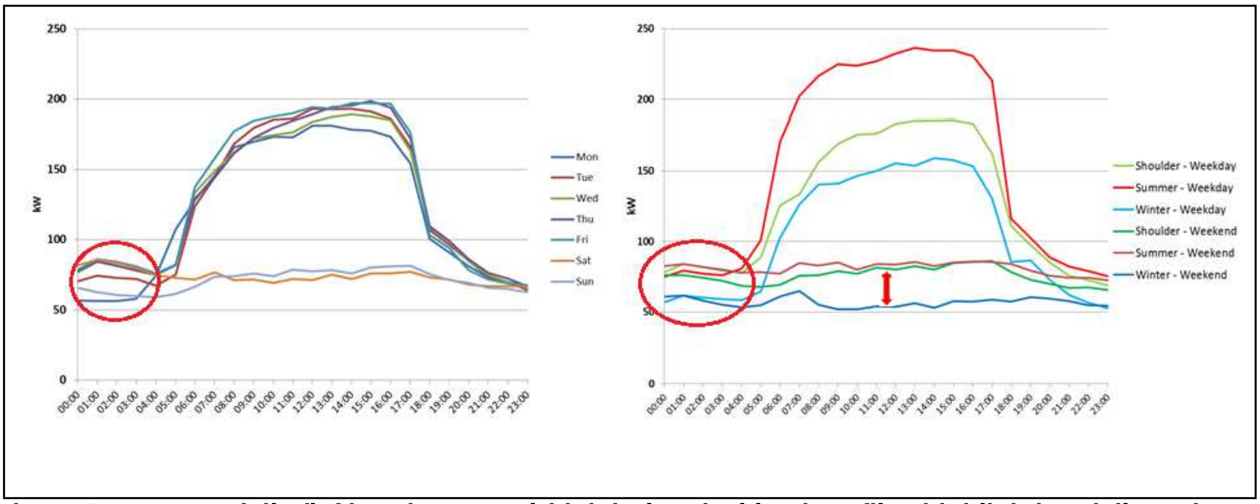

Figure 3: Average daily (left) and seasonal (right) electrical load profiles highlighting daily and seasonal variation in the base load

Site inspections were conducted over a course of several months and at various times of the day and night to observe the building in its different modes of operation. The end use breakdown presented in Figure 4 as constructed according to the findings of the site inspections. A Sankey flow diagram (Figure 5) was also produced to help illustrate the diversity of energy sources and complementary systems within the building.

It is noted that the sub-metering system could not significantly inform the breakdown of base building services due to inadequate coverage and poor data quality from some meters.

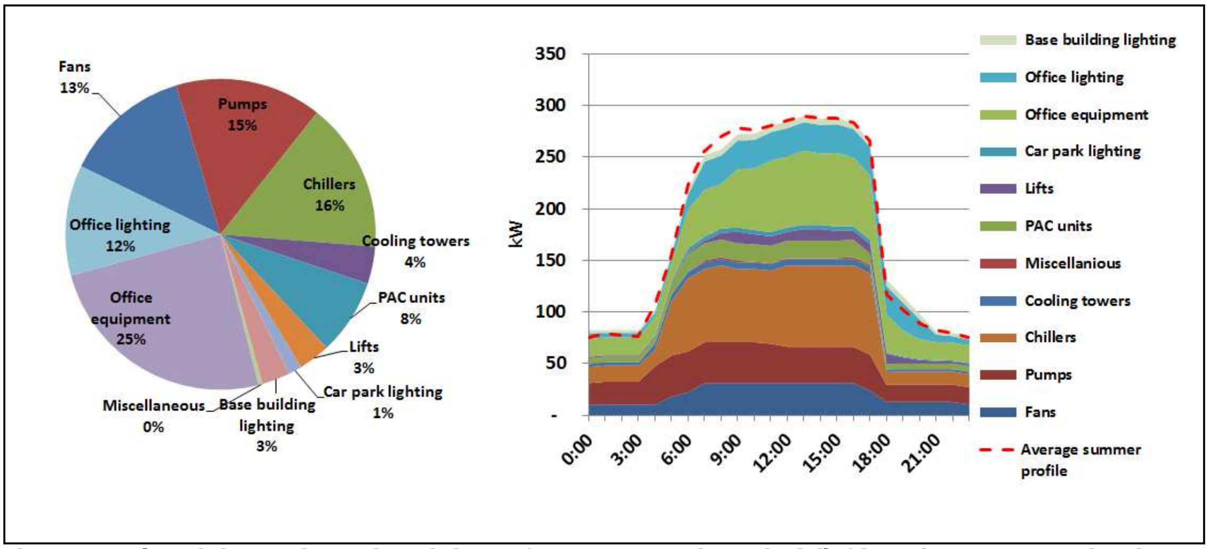

Figure 4: Electricity end use breakdown for a 12 month period (left) and an average business day in summer (left).

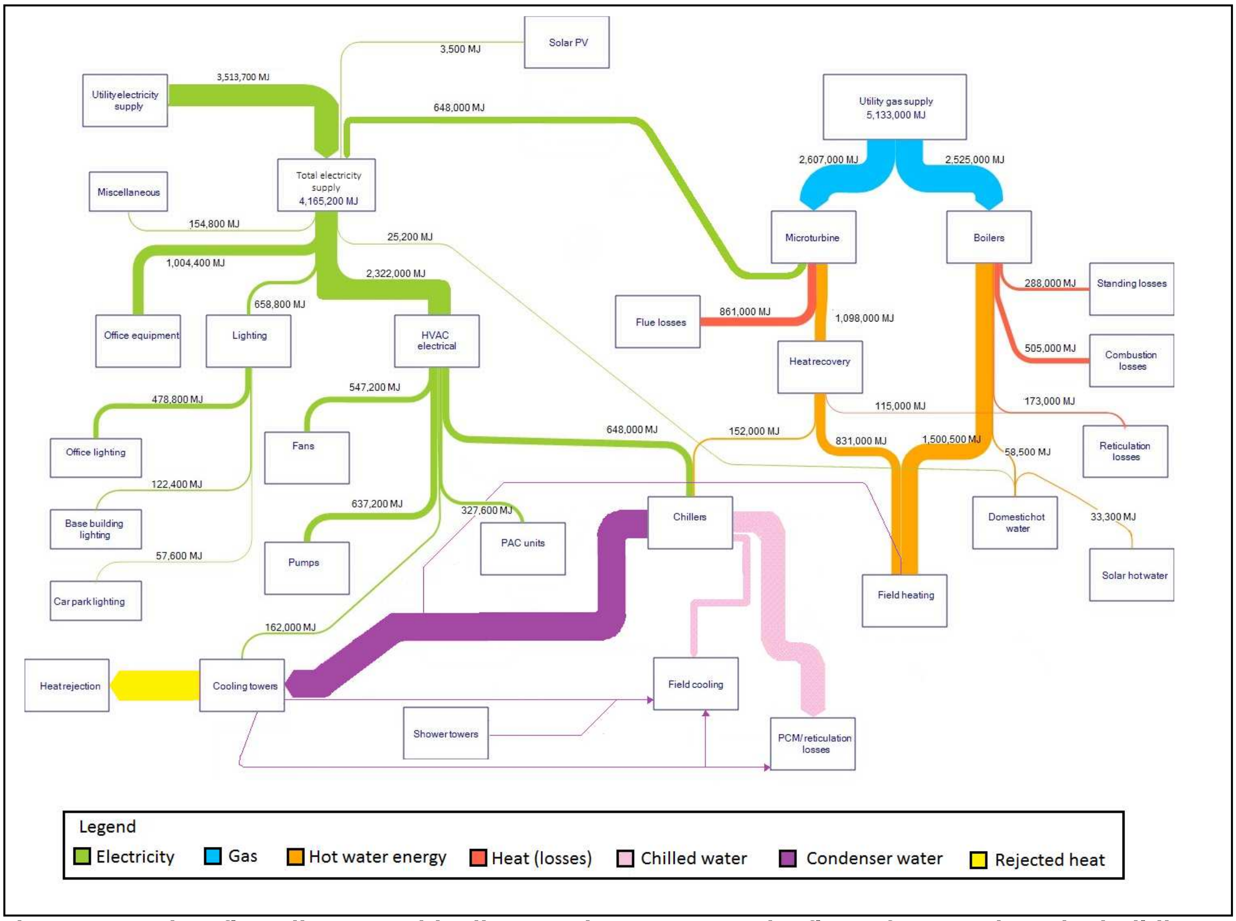

Figure 5: Sankey flow diagram. This diagram demonstrates the flow of energy into the building and throughout its sub-systems. The diversity of energy sources and uses within the building is evident, as well as the degree of energy transfer and heat recovery between the range of sub-systems. Note that thermal energy flows in the CHW and CDW networks are not quantified.

5. Key issues

The key issues preventing CH2 from realising its potential were found to be in the strategies and commissioning of its HVAC controls. Widespread opportunities for optimising control were observed and could broadly be categorised into three groups:

- *Priority of cooling modes.* One way in which CH2 is unlike most buildings is that it has several different ways of generating cooling to provide to the floors. The source of cooling can either be via absoprtion chiller heat recovery from the micro-turbine, the screw chillers, the cooling towers or the shower towers. Production of cooling can either be after-hours and stored within Phase Change Material (PCM) tanks or delivered directly during occupied hours. Observations of the building through a range of conditions revealed that the system often failed to prioritise the most efficient cooling mode available. This regularly resulted in significant energy wastage overnight for charging of PCM tanks, which proved to be the issue responsible for the overnight operation (Figure 3). More importantly though, poor consideration of cooling modes meant the building was largely operating without an economy cycle thus leading to excessive use of the electric chillers.

- *Optimisation of HVAC parameters.* A number of the temperature, flow and pressure set points that the building's air and water systems were operating to were fixed in spite of variable demand conditions. Examples included constant pressure control for chilled water and heating hot water pumps, constant flow control for air handler fans and constant water temperature control for chiller plant condenser water.

- *Tuning of HVAC operation.* A range of smaller operational issues were identified that summed up to a reasonable quantity of lost energy for the site. Such issues included general exhaust fans running when not required, car park ventilation fans running irrespective of CO set points, pumps running when there was no heating/cooling within the fluid they were circulating, heat exchangers (HEX) opening the primary valve without the secondary valve and so on.

A comprehensive revision of the strategies and commissioning of the HVAC controls was recommended to address these issues, including improved economy cycle operation, variable setpoints for key water and air systems and a general tightening up of HVAC control to avoid wasteful operation.

However, the physical components of a system must be operating reliably for controls measures to achieve their full potential. Observations of CH2's plant suggested the system was generally in good working condition but there was evidence of a modest range of less visible issues that may have been preventing optimum performance. The majority of these issues were consistent with the usual failure modes of commercial HVAC systems, including air within the water networks, instances of dubious sensor accuracy, valves failing to seal, compromised HEX efficiency and poor performance of PCM tanks. A tune up process was recommended to help mitigate the risk they posed to the performance of the building.

6. Examples of control opportunities

A series of screenshots from the BMS are presented below with notes against the opportunities they highlight.

6.1. Erroneous cooling system operation during business hours

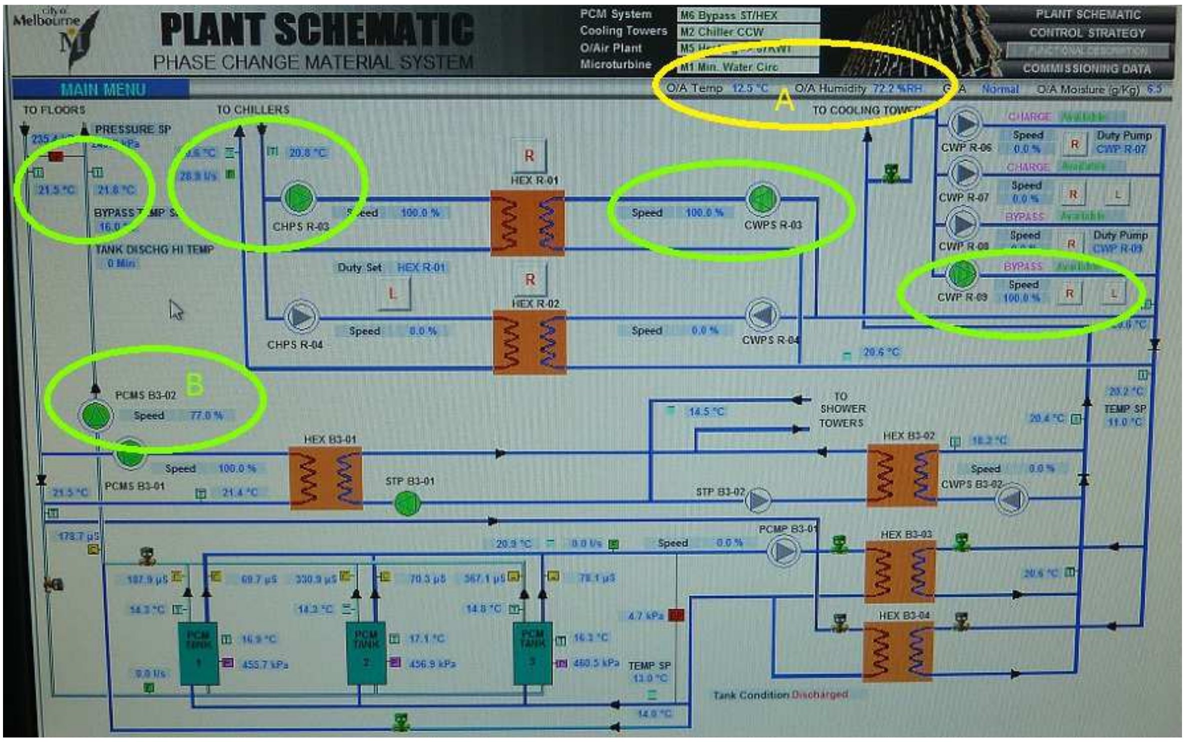

Figure 6: Cooling system operating when "free cooling" is available from ambient conditions

Figure 6 demonstrates the building's cooling system operating on the 27th July 2012. The following opportunities for improvement were observed:

- As noted in the yellow circle labelled "A", the outside air conditions at this time were 12.5°C and 72%RH, corresponding to a wet bulb temperature of approximately 10°C. In these cool conditions, the cooling towers are capable of providing sufficient cooling to the building with no need for the chilled water plant. This opportunity exists for most of winter but was overlooked by the system's control strategy.
- As noted in the green circles labelled "B", there were a number of pumps operating at this time apparently for no purpose. The absorption chiller had faulted out of operation, preventing the cooling system from providing any cooling. However, the failure was not communicated to the pumps and thus they were each running to circulate room-temperature water throughout the building.

6.2. PCM charging with chilled water

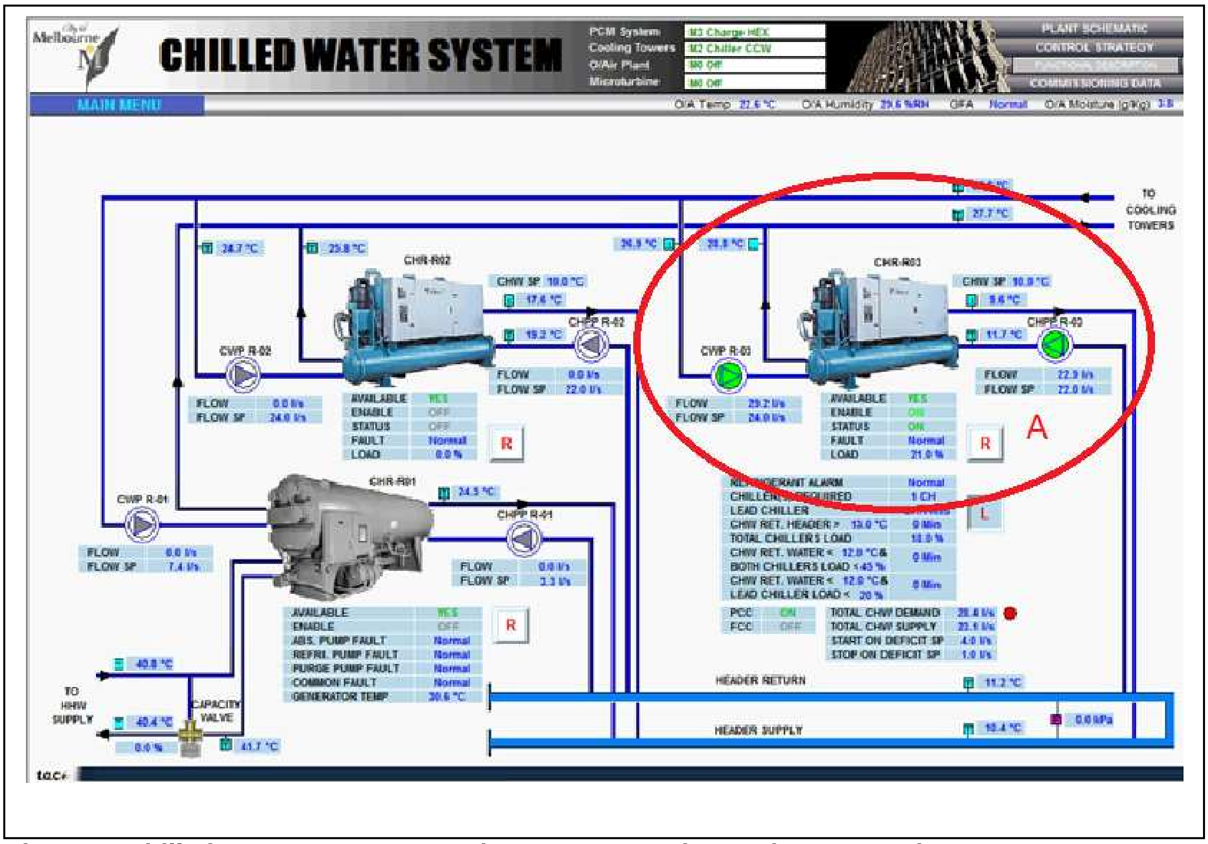

Figure 7: Chilled water system operating at 04:00 to charge the PCM tanks

Figure 7 demonstrates the chilled water system operating at 04:00 on the 21st of November 2012. The chillers were found to be operating overnight to charge the PCM tanks. This operation appeared to occur regularly throughout the shoulder and summer months between the hours of 00:00 and 06:00 on business days. The design intent of the PCM charging process is to take advantage of cool overnight conditions and charge the tanks with the cooling towers to avoid having to use the chillers during the day ([5]). In normal circumstances there would be little advantage in running the chillers overnight to charge the PCM tanks but if they were operating ideally there would not be a great penalty either. However, there appeared to be a high level of loss associated with this operation. Logs of the charging and discharging process were plotted against the average tank internal temperature in Figure 8.

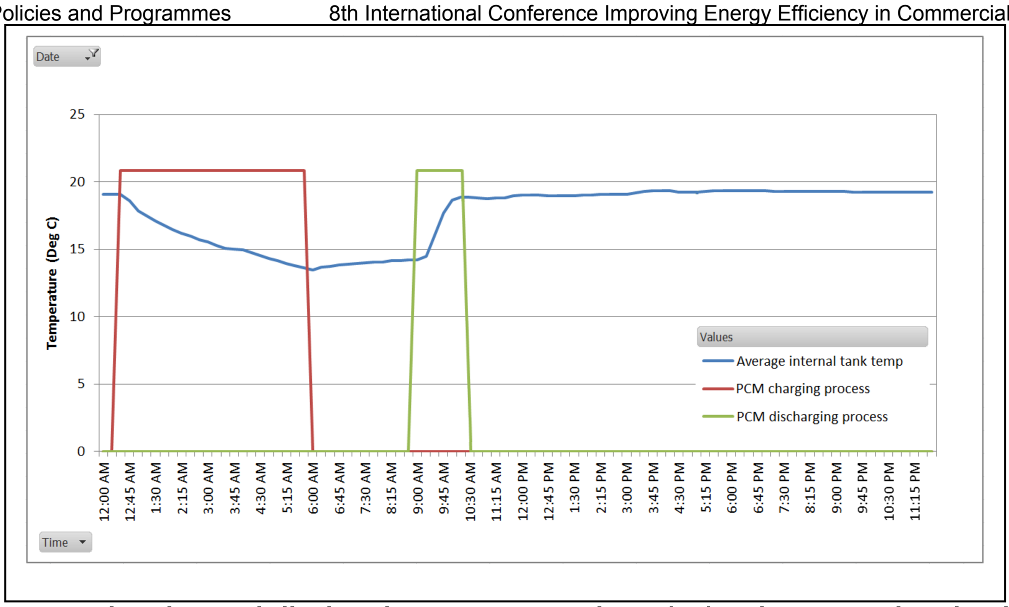

Figure 8: PCM charging and discharging process on the 14/11/12 demonstrating the disparity between charging and discharging times

The following observations were made:

- Whilst the charging process (signified by the decreasing tank temperature) lasted for approximately five hours from 00:00 to 05:00, the tanks were fully discharged (signified by increasing tank temperature) after one hour upon start up.
- The temperature is continuously decreasing during the charging process. The temperature of a phase change material remains constant whilst the material is under-going a phase change (changing from liquid to solid). That the tank temperature was continuously decreasing during the charging process implied that there was no phase change within the tank; i.e. the chilled water was merely cooling the material down in its existing phase (most likely liquid). The thermal storage capacity of the tank relies on the material's nature to absorb coolth as it changes from liquid to solid phase; thus the tanks provide minimal storage without the phase change process.

6.3. Erroneous operation of heating plant and air handling plant

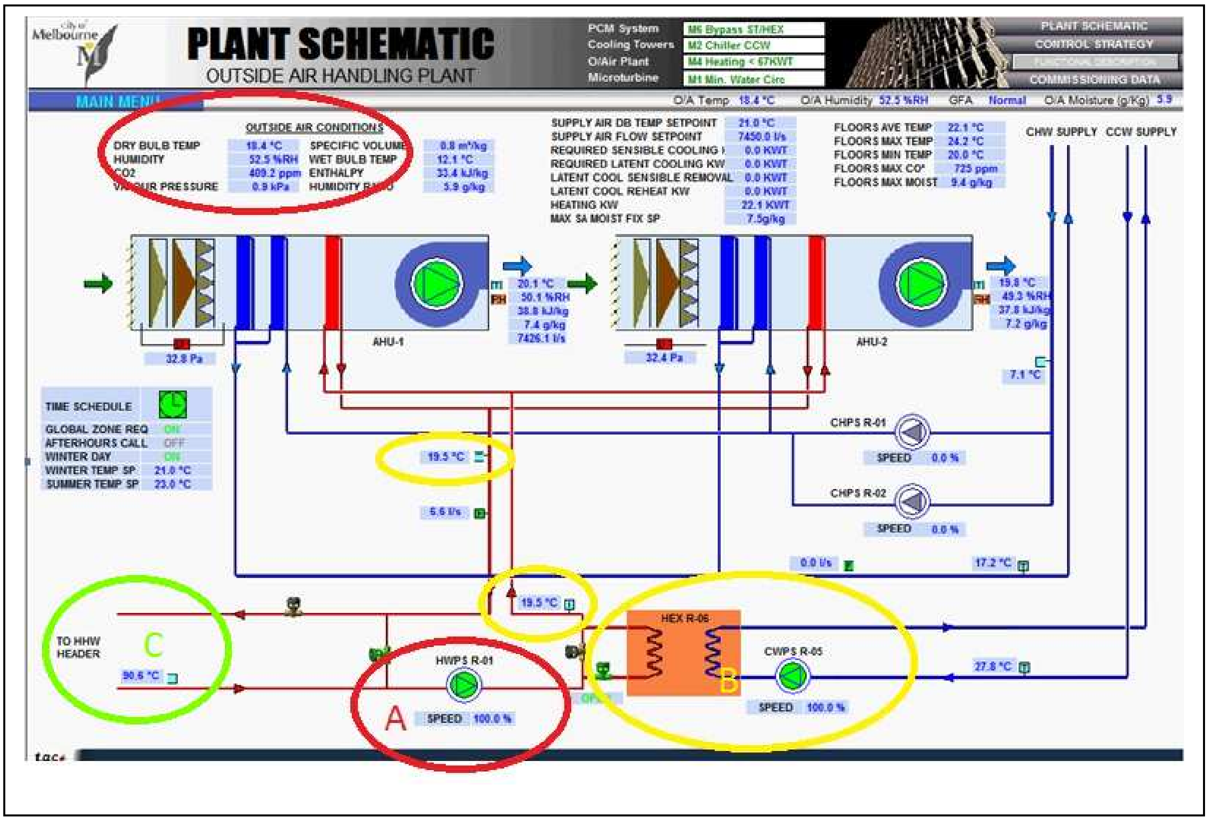

Figure 9: Air handling plant engaging the heating system in mild conditions

Figure 9 demonstrates the outside air handling plant operating on the 18th October 2012. Several issues were observed with its operation:

- As circled in red and labelled “A”, the heating pump had been engaged for the air handling plant despite the mild ambient conditions (18.4°C). Heating should not be required in an office building with ambient conditions above 18.0°C.
- As circled in yellow and labelled “B”, the system elected to operate the heat reclaim pump from the condenser water loop to serve the heating needs of the air handlers at this time. However, the temperature of the flow into the HEX, out of the HEX, into the AHUs and out of AHUs was each measured at 19.5°C, indicating there was no transfer of heat occurring in the system and thus the pumps were not achieving anything.
- As circled in green and labelled “C”, the heating hot water network was engaged at this time and inspection of the BMS heating demand indicated that the AHU system was registering a demand on the heating hot water plant despite not using the heating hot water.

6.4. Constant speed pumping

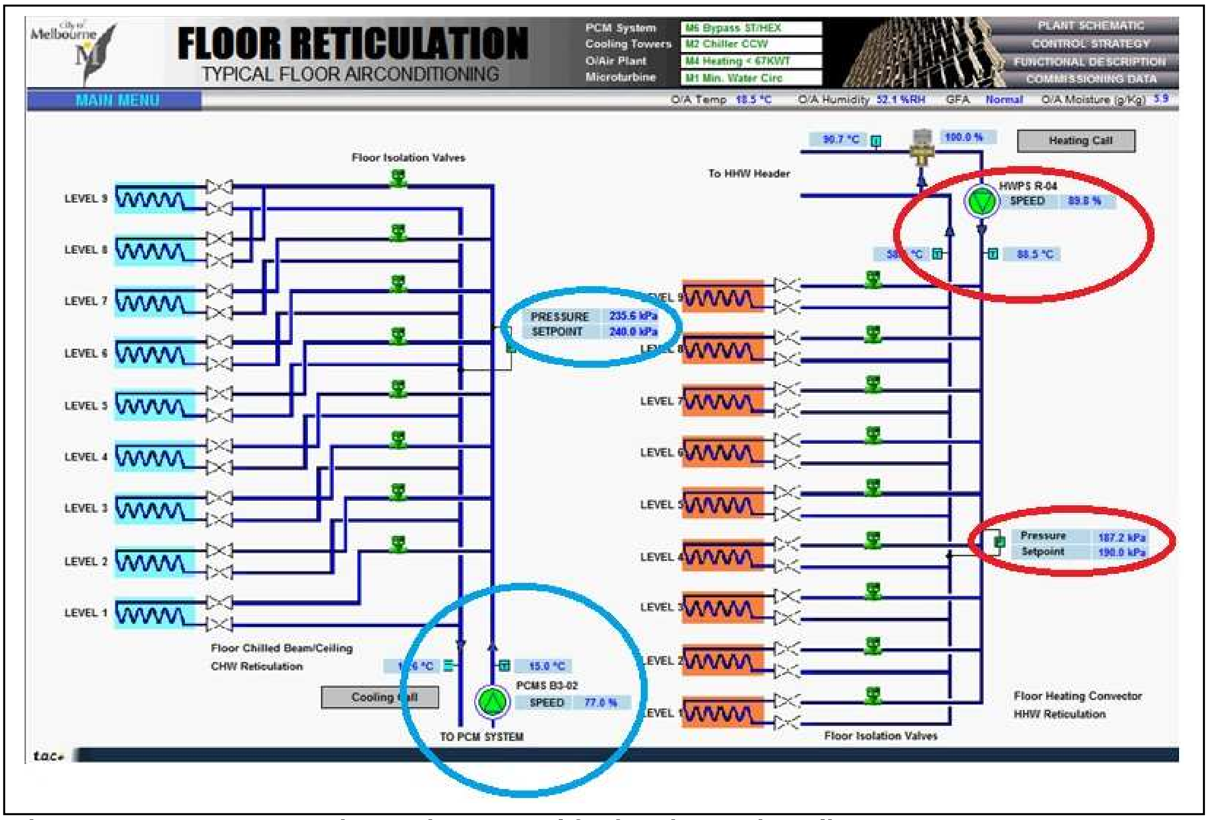

Figure 10: Constant speed pumping control for heating and cooling systems

Figure 10 presents the operation of heating (in red) and cooling (in blue) reticulation in the building on the 18th October 2012. These pumps were observed to be operating at the same speed across a range of different internal and ambient conditions. Introducing dynamic resets to the pressure set points was recommended to help them turn down to meet demand, which would also apply more broadly to other air and water systems as well.

7. Measures for implementation

The report was delivered to the building owner in December 2012 with recommendations made for wholesale revision to the HVAC controls in addition to a suite of hardware tuning items and minor retrofits. At the time of writing the first stage of measures are in the tendering phase and scheduled to commence implementation during FY13/14. They are presented in Table 2.

Table 3: Short to medium term measures for implementation

Measure	% Energy saving	Payback (yrs)	Base building NABERS star impact
HVAC controls revision of re-commissioning	19.7%	5.2	1.14
Upgrade supplementary CDW system to variable flow	1.4%	9.3	0.13
Optimise after hours DHW servicing	3.9%	8.1	0.06
Back of house lighting controls	0.3%	22	0.02
Sub-metering verification and monitoring	n/a	n/a	n/a
Total	**25.2%**	**7.2**	**1.36**

Error! Reference source not found. demonstrates the measures improving the base building's rating to 4.5 stars. However, it is important to note that the savings were conservatively calculated as what we expected to be available from an "install and leave it" type approach. We anticipate that an intensive process of monitoring and tuning will reveal greater potential from the building's existing systems.

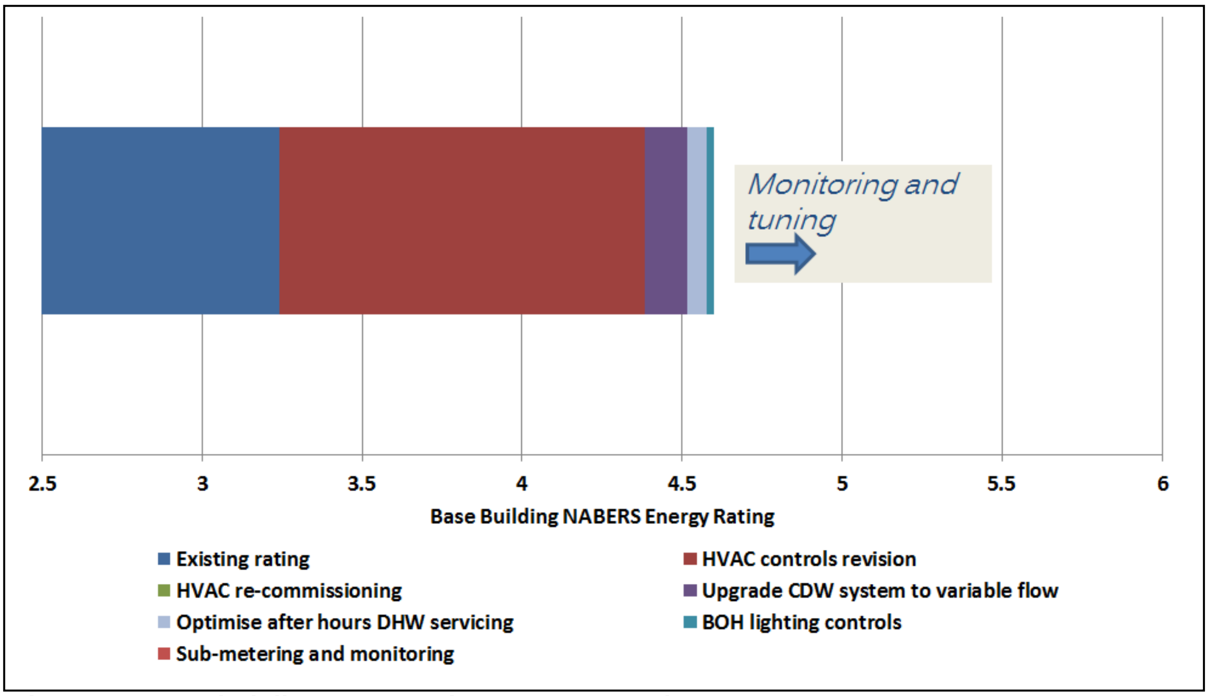

Figure 11: Base building NABERS improvement path

Crucial to the success of this project will be a functioning sub-metering system to inform a critique of each of the building's features as they are plugged in and out of the control strategy. This process will serve to provide a blueprint for how the building's complex array of sub-systems can best collaborate with each other. Furthermore, with this information the building will finally be in a position to provide feedback to the industry on the performance of the experimental technologies it features.

8. Conclusions

1. CH2 is currently performing well below its potential due to the state of the HVAC controls. It appears that the complexity associated with the building's web of relatively unfamiliar sub-systems has led to a range of flawed strategies and operational issues.

2. The building is an excellent illustration of the importance of optimising control strategies and commissioning control behaviour for sub-systems not only individually but also in their operation as a whole system and under numerous scenarios.

3. The building is expected to achieve 4.5 stars NABERS base building performance with the measures currently intended for implementation. Further improvement is expected to be realised with intensive monitoring and tuning.

4. Upgrade of the building's sub-metering system, combined with a staged process of implementation and measurement is necessary not only to optimise the building's operation but also to inform the industry on the performance of its more experimental technologies. This review marks the beginning of a project from which much more will hopefully be learnt regarding the performance of its many features.

Acknowledgements

We would like to acknowledge the keen assistance of Michele Leembruggen (Sustainability Branch), Allen McCowan (Property Services) and their colleagues within the City of Melbourne, as well as Matt Waller of Transfield Services and Peter Collins of Schneider Electric.

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Smart energy performance indicators for live historical and normative feedback systems

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Abstract

Communicating building energy performance to building users has been identified as a significant opportunity to support behaviour change. This research pursues the concept of continuous, automated feedback designed to support motivated building users to learn how their behaviour impacts building energy performance.

Automated energy consumption data collection presents an opportunity to develop approaches for continuous feedback systems. However, energy performance is a complex notion and consumption data alone are not suitable to convey performance. In order to be of use, performance indicators designed specifically for providing feedback to building users must reflect changes in user behaviour which may be small relative to total consumption.

A new building energy performance indicator is proposed based on the concept of continuous improvement. The indicator combines the benefits of historic and normative feedback by producing a normalised index of improvement or deterioration over time. The indicator is also well suited to communicating building energy performance in a user-friendly way.

The indicator is based on a predictive consumption model fitted to data for a rolling baseline period. The scale of the indicator is defined in terms of the variation in baseline model residuals. This allows for a direct comparison between buildings on the basis of improvement or deterioration from the baseline performance. A direct comparison can be made even between very different buildings.

A case study of five university buildings is presented. Consumption is predicted at half-hourly resolution using a variation of a standard variable degree day model. The indicator is calculated for each half hour beyond the initial 365-day baseline period on a rolling basis with a new baseline model being calculated each week.

The indicator reflects even small changes to regular consumption patterns, both persistent and transient. Persistent changes are absorbed into the rolling baseline model after a few months. Critically the indicator is sensitive enough to detect small changes in consumption patterns and can be compared between buildings. As a feedback tool the indicator has the benefit of having a common scale and being comparable across buildings.

Introduction

In recent years there has been much interest in the use of feedback systems to encourage energy behaviour change but very little literature on the design of feedback systems in the non-domestic setting. Energy consumption is largely invisible to building users [1] and energy feedback is primarily useful because it makes energy “more visible and more amenable to control” [2].

The behaviour of building users has an important influence on energy consumption. Very often simple, low-cost or zero-cost changes to occupant behaviour can have a significant effect on building energy consumption. These so called **low-hanging fruit** are a great opportunity for motivated building users to take meaningful, autonomous action to save energy [3]. However, if a space is comfortable and equipment is working, the effects of energy consumption are not obvious to building users. Only the services provided by energy are visible, if they are removed (e.g. the space becomes uncomfortable or equipment fails) then a user will notice the impact immediately. Information about the energy consumption required to deliver these services is usually not available.

Half-hourly consumption data from automated meter reading (AMR) systems and smart meters are becoming ubiquitous in larger public buildings and modern building energy monitoring systems collect data at least every half an hour. These 'live' data provides a valuable resource for energy management. They can be used to diagnose problems as soon as they occur, to identify opportunities to reduce energy wastage and to measure and verify the savings from energy efficiency interventions. They can also be used as a means to communicate energy performance to building users and the wider population of stakeholders.

It is desirable to provide feedback systems that enable building users to benefit from these high quality datasets and to directly see the impact of their behaviour on energy performance in more or less real time. In this work "continuous energy performance feedback systems" are defined as continuous information loops in which information about the energy performance of a building in the past and present is used to influence present and future energy performance. A feedback system allows users to learn the impact of their behaviour and enables them to adjust their behaviour to reduce energy consumption. Users can experiment with modifications to their behaviour and see the impact of these changes directly and immediately.

The methodology presented in this paper was developed as part of the EU-funded SMARTSPACES project [4]. The SMARTSPACES project is developing ICT-based services at eleven pilot sites across Europe, each designed to save energy in public buildings. The methodology presented underpins the SMARTSPACES services provided in the Leicester pilot site in the UK [5].

The Leicester pilot site services are designed as a continuous energy performance feedback system, a schematic of this is provided in Figure 1. The main components provided by the system are a metering and communications system, a data modelling and analysis system and web-based visualisation and user engagement tools.

The metering and communications system in Leicester has been in place for over a decade providing high quality, high resolution (half-hourly) electricity, gas and water consumption data. The final link in the feedback loop is user engagement which is delivered primarily via a modern, open source online discussion forum. A detailed discussion of these aspects of the system is outside of the scope of this paper.

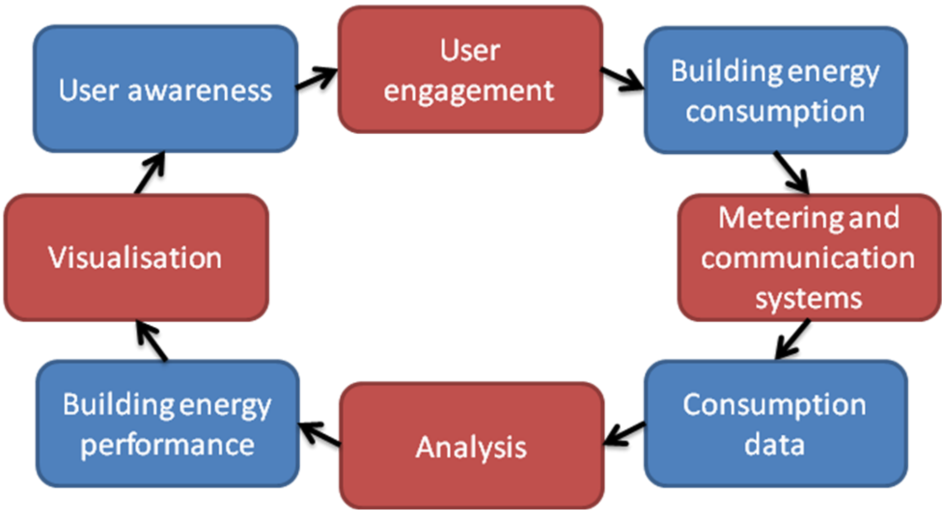

Figure 1: Schematic of data and information flowing in an energy performance feedback loop

The primary subject of this work is the data treatment components including analysis and visualisation. Automated modelling and analysis tools process historical raw data as a way to provide context for recent consumption and to extract the most salient information from the available data. Another critical and carefully designed component is the web-based user interface which provides visualisation tools necessary to deliver useful information directly to the building user in a usable form.

Modeling and analysis

Feedback resolution and timing

For a continuous energy performance feedback system to be effective, it must provide information at a temporal resolution suitable to allow users of the system to distinguish between different behaviours. For example, a feedback system that worked on a daily resolution would provide a single feedback report representing the entire day. If the user required feedback on overnight energy performance then this will be aggregated with daytime performance and difficult to resolve. Similarly, feedback provided at weekly resolution would obfuscate the effects of weekly occupancy cycles. In this case the system is based on half-hourly data and is designed to provide feedback at this resolution. That is, users are provided with information at half-hourly resolution.

The data collection infrastructure which provides the energy consumption data is configured to generate half-hourly data. However, the system only communicates these data at three-hourly intervals. As such the information available can be up to three and a half hours out of date. This is a critical aspect of any such system. Were data provided less frequently (e.g. once a week or once a month) then the users would need to remember what they were doing last week or last month in order to map the feedback to their knowledge of activities in the building. More frequent updates provide timely feedback and remove this barrier to information flow. In this respect, providing feedback at sub-daily resolution has a huge advantage.

Context-free information

The aim of the smartspaces project is to create a feedback system to provide all building users including visitors, staff and energy professionals with usable information. Feedback systems rarely provide simple raw consumption figures. Indirect feedback, where the data have been processed in some way, is more common [2]. In this paper we describe a somewhat extreme approach to data processing.

For most building users, we must assume that energy is not an important issue. As such it is unlikely that users will commit significant time and effort to interpret any feedback provided. Ideally, the information delivered should be context-free, requiring as little prior knowledge and interpretation as possible. Providing information that requires sophisticated interpretation is a major barrier to feedback. Reducing the context improves the flow of information around the feedback loop. For example, providing information about energy consumption in units such as kilowatt hours (kWh) is meaningless unless the audience is also aware of the context (i.e. what is a kWh).

There are many examples of attempts to communicate in more familiar units (e.g. “enough energy to make x cups of tea”). This is an example of contextualizing the information. In this case the context is moved from knowledge of kWh to knowledge of tea. By combining information with its context a modified version of the information is produced with a reduced or modified contextual requirement. When manipulating data in this way it is important to consider what context an audience will be aware of in order to produce a suitable form of information. The audience no longer needs to know what a kWh is, but are expected to be familiar with tea.

In this research a more esoteric context of building energy consumption is explored. Providing absolute energy consumption information is reliant on knowledge of how much energy a building ***should*** be consuming under the current circumstances, which in turn requires knowledge of the current circumstances. Without this information, the consumption data alone cannot be easily interpreted. Put another way, energy consumption (the dependent variable) depends on circumstances such as weather and occupancy (independent variables). To determine whether the current consumption is high or low requires knowledge of weather and occupancy and a knowledge of how the building typically responds to these variables.

Contextualizing consumption in this way might involve placing the value within a range of expectation. But it is desirable to provide more than simply raw data. We can reduce the complexity of the message and provide higher-level information. This can be done by converting consumption to a simple message reflecting performance on a scale from good (lower than to be expected under the circumstances), through neutral to bad (higher than expected). This context-free information can be interpreted without prior knowledge of the building. The remainder of this section describes a method based on a statistical model of historical consumption data for creating a robust indicator of energy performance that can be used in a continuous feedback system.

An instantaneous performance indicator

Raw consumption data offer little to the casual observer. Time and effort is required to look closely and understand the patterns. Figure 2 shows two years of half-hourly electricity and gas consumption for four university buildings (outside air temperature is also indicated in red). The data are relatively complicated. Several patterns can be observed in the data, consumption varies seasonally with temperature affecting heating and availability of natural light affecting demand for artificial lighting. At a shorter timescale there are weekly and daily cycles relating to occupancy.

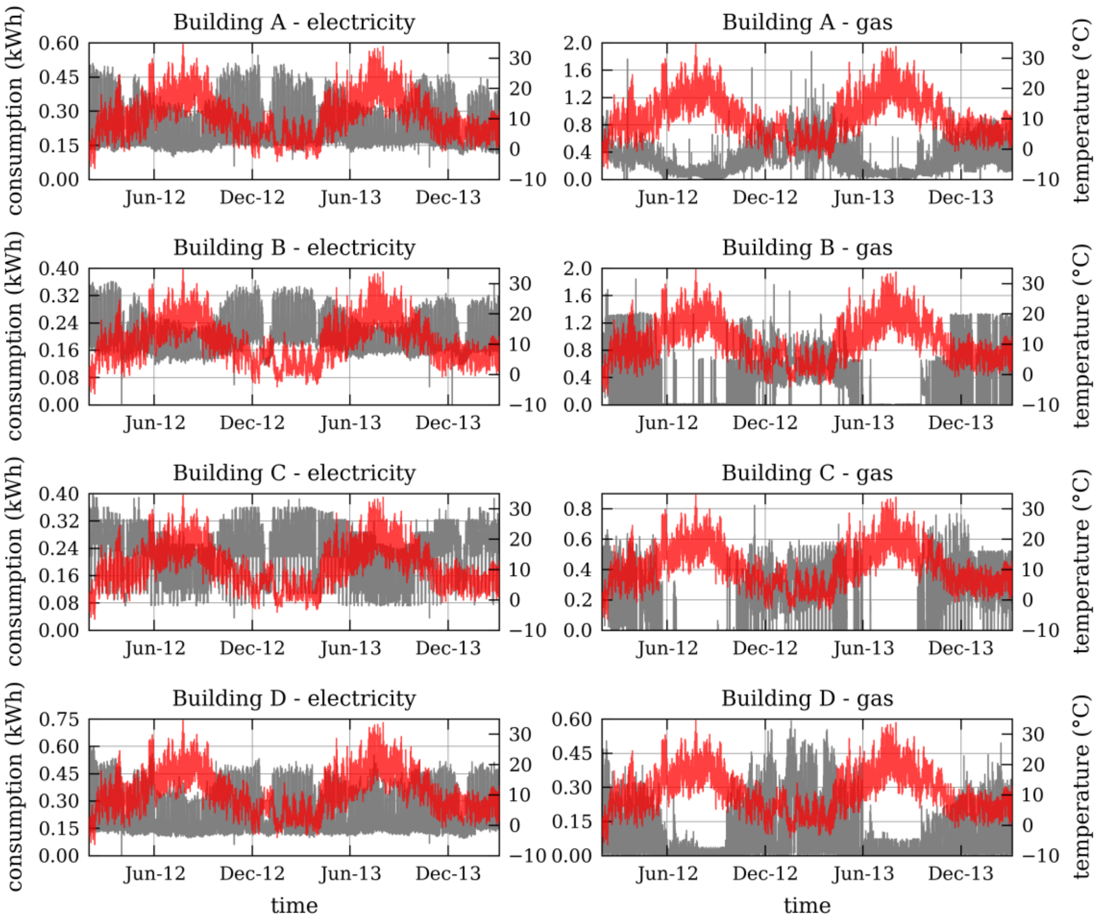

Figure 2: Raw energy consumption data for four buildings (outside air temperature in red)

It would be very difficult for a user unfamiliar with energy data to extract any useful information from a graph of energy data. In any case, as discussed above, energy consumption is not the information we want to communicate. Even for an experienced analyst, an assessment of current performance would require time and effort to produce.

To communicate energy performance we need to define it. For the purposes of this paper, "energy performance" is defined simply as the absence of energy wastage. The energy consumption of a building comprises consumption necessary to deliver useful energy services plus energy wastage. Whilst absolute energy performance is difficult to establish from raw consumption data, relative performance from one period to another is not so difficult if we make certain assumptions. A historical comparison can be a useful proxy for changes in energy wastage. If consumption falls below the historical norm then savings can be said to have occurred. Conversely, wastage is indicated by an increase in consumption above historical norms. A historical comparison is used as the core measure of energy performance or more accurately "energy saving performance".

Energy saving performance

The International Performance Measurement and Verification Protocol (IPMVP) (EVO 2007) defines a methodology for carefully and precisely quantifying change in consumption patterns due to energy interventions. In particular the protocol defines a baseline period before the intervention and a test period, after the intervention. The baseline is used to establish the pattern of consumption before the intervention was implemented. IPMVP can be implemented with simple regression models fitted to data collected in a baseline period. The standard model is the variable based degree day model, Figure 3 shows this model and several variants.

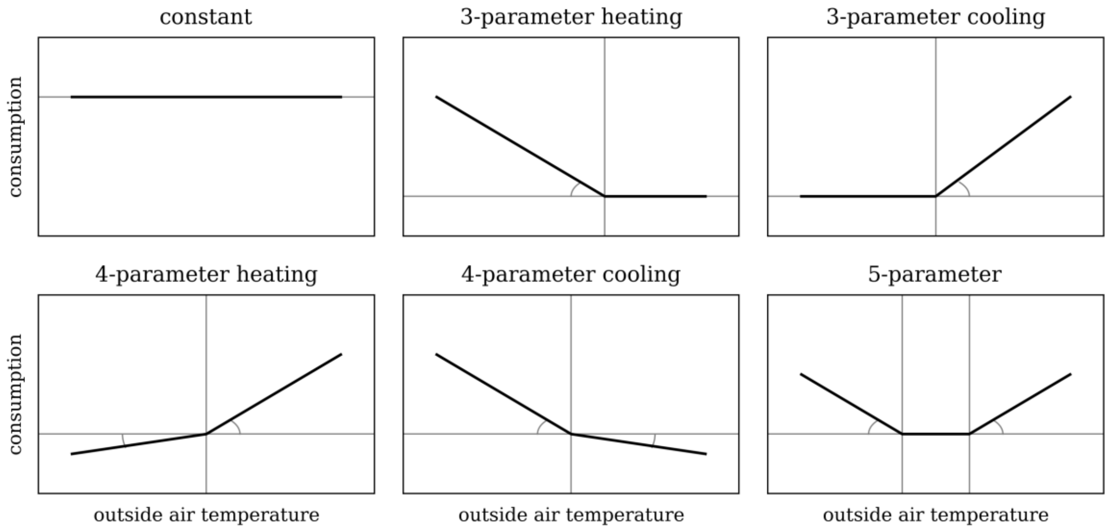

Figure 3: Common variations of the variable-base degree day model

A common IPMVP approach is to fit an appropriate model to data collected in a baseline period and to use this baseline model to forecast forwards into the test period (the period in which savings are to be verified). This is typically done as a one-off calculation where the baseline period is the period covering several months before an intervention was implemented and the test period covers several months after the implementation.

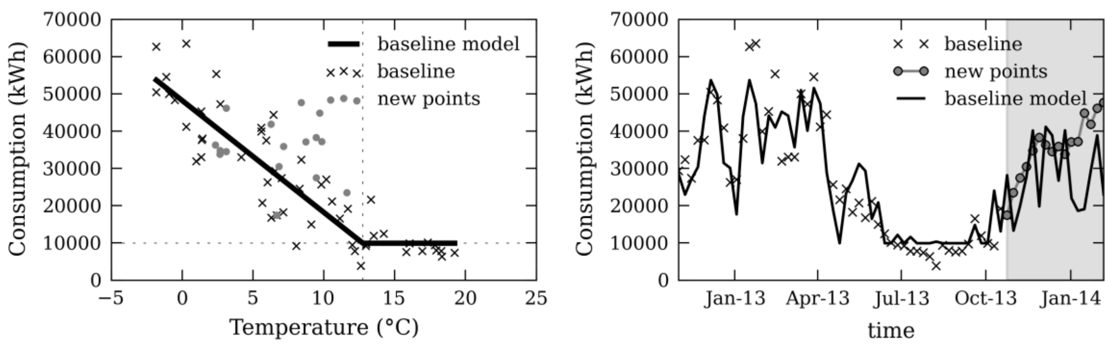

Figure 4: Example energy saving calculation with baseline model and forecast into test period

Savings are calculated as the difference between measured consumption in the test period and the forecast consumption which provides an estimate of what consumption **would have been** without the intervention. Figure 4 shows an example calculated with weekly data. The chart on the left shows a three parameter heating model (the black line) fitted to baseline data (the black crosses). Data from the test period are also plotted as dots. The right side of the figure shows the same model and data transferred onto the time axis. It can be seen that the data collected in the test period (dots on grey background) are above the forecast consumption. This indicates an increase in consumption presumably caused by either increased energy wastage or an increased demand for energy services.

The same approach can be extended to a continuous monitoring scheme where every half-hourly data point is compared to a consumption model fitted to the previous 12-month baseline period. To reduce the computational overhead, this can be simplified to a scheme where a model fitted to a 52-week baseline period is used to forecast one week of half-hourly consumption. Before discussing this method in any more detail, it is useful to describe the actual models used in a concrete implementation of the scheme.

A simple, half-hourly consumption model

In order to model half-hourly consumption patterns it is necessary to extend the consumption models described above by taking occupancy into account. At half-hourly resolution the main feature of consumption data is the daily and weekly occupancy patterns. Figure 5 shows a single week of data for each of the example datasets. Consumption patterns are dominated by the effects of occupancy. The occupancy pattern shown is broadly consistent for each building as changes to opening hours are rare. This pattern of consumption must be predicted accurately for the scheme to be useful.

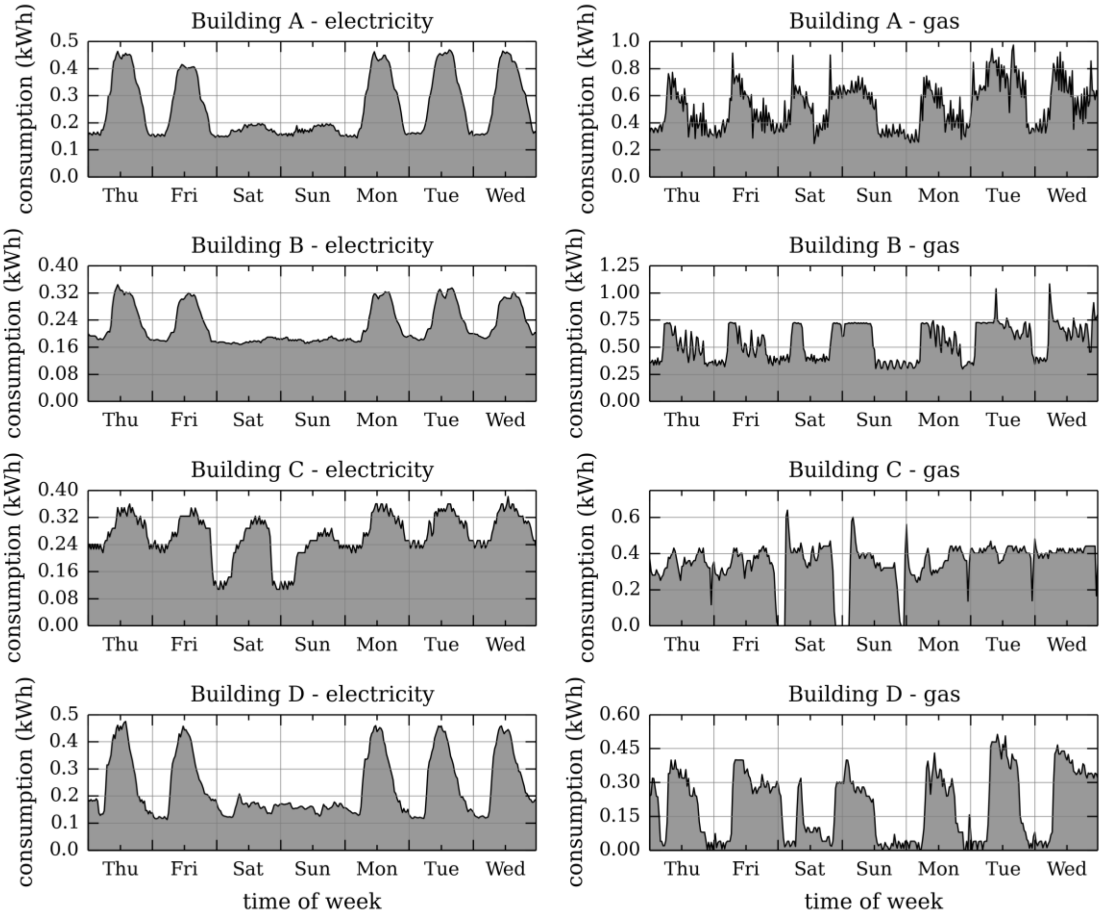

Figure 5: A single week of electricity and gas consumption data for the example datasets

To model this pattern, baseline data are split into 336 subsets, one for each half-hour period in the week (i.e. a combination between time of day and day of week, e.g. one subset only contains data from Mondays at 09:00). Each subset contains 52 data points. The baseline model is created by fitting an independent model to consumption data within each of the subsets. This generates 336 individual sub-models. To generate a prediction from a data point in the test period, the appropriate sub-model is identified and used to generate the prediction.

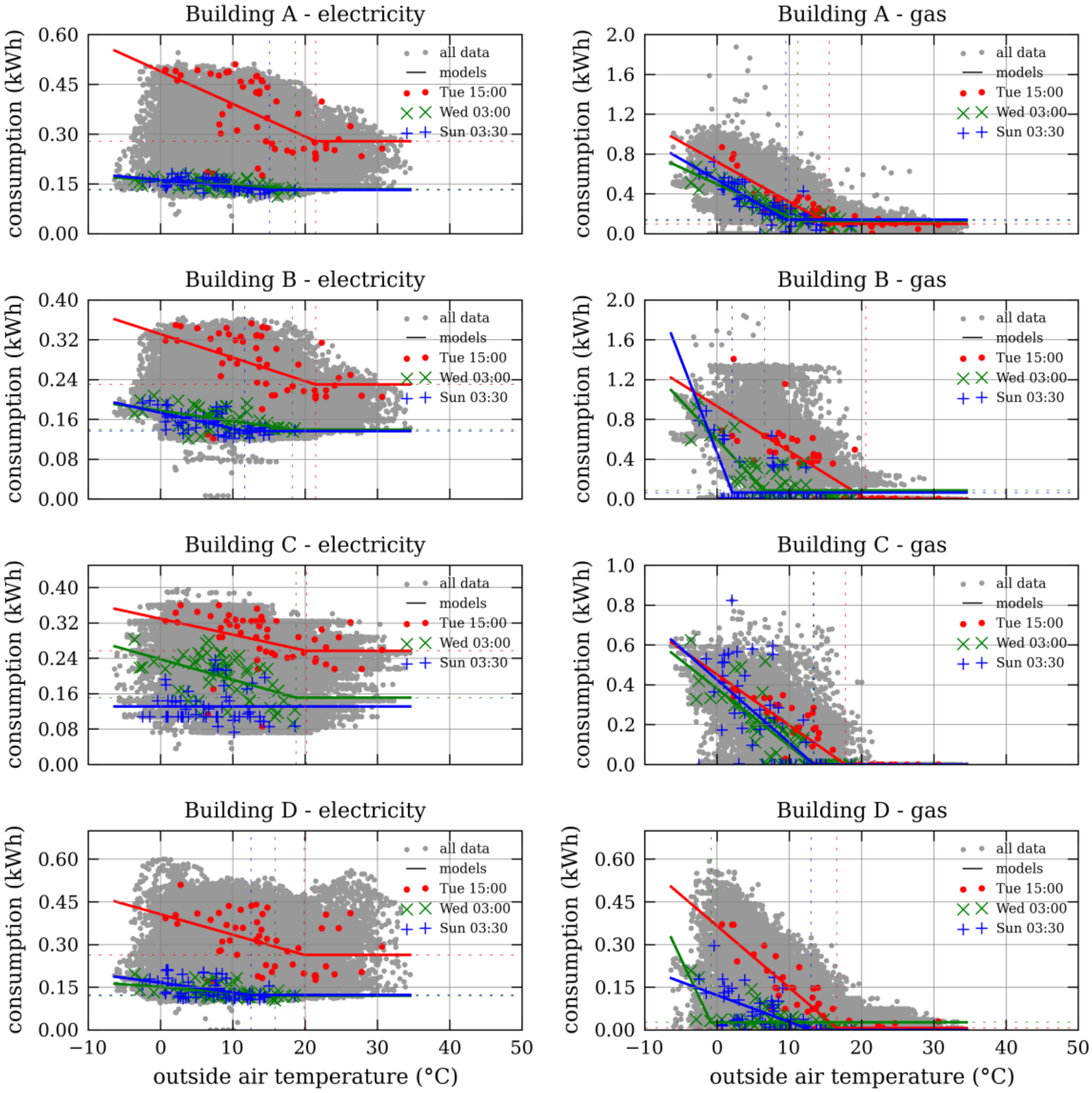

Figure 6: Three sub-models (Tue 15:00, Wed 03:00 and Sun 03:30) for the example datasets

Figure 6 shows how the model fits to data from different buildings. Only three periods are shown to avoid confusion (the full set of 336 models would be difficult to visualize in this way). The blue line and points indicate a weekend overnight period (03:30 on Sundays) when the buildings are expected to be unoccupied. In most cases this period is shown to be the lowest consumption period with lower values for the model parameters. The green line and points indicate a mid-week overnight period (03:00 on Wednesdays) when the buildings are also expected to be unoccupied. In most cases this model is very similar to the weekend equivalent but some buildings show systematically higher consumption during this time indicating different control strategies and possibly occupant behaviour. The final period highlighted in red shows an occupied period (15:00 on Tuesdays) and shows a clear difference in model parameters during occupied and unoccupied periods for most buildings. Interestingly, the gas consumption shows a far smaller difference. This is likely due to high setback temperatures and relatively poor heating control.

It should be noted at this point that the type of sub-model applied is determined by an intelligent algorithm [6] which selects either the constant model or the three-parameter heating model (see Figure 3) based on the Bayesian Information Criterion. This allows for a more parsimonious fit to the data and helps avoid spurious effects of over-parameterized models. This can be seen in the electricity consumption of building C where a constant model has been chosen for the data from Sundays at 03:00. An automated method is necessary when working in a live information system.

Figure 6 only shows three sub-models for each dataset. To visualize the complete model requires some more innovative design work. To create a visualisation, each model was used to generate a matrix of predictions covering each of the 336 time periods and a range of temperatures from -5°C to +35°C at 0.5°C intervals. This grid of predicted data was then converted into a false colour image. The resultant visualisations are shown in Figure 7.

Figure 7 reveals some interesting features that are not easily visible in the raw data. The model represents a simplification of the pattern of consumption in each building. It is clear that there are similarities between the buildings in both their electricity consumption pattern and their gas consumption pattern. Building C stands out as using electricity both on the weekends and into the evenings. This is expected as it is a Library and is occupied almost 24 hours a day, 7 days a week. As in Figure 6 we can see a strong correlation between electricity consumption and outside temperature in all buildings. This may be due to pumps and fans of the heating systems or may be mostly the impact of seasonal availability of natural light.

During warmer periods electricity consumption maintains a strong correlation with occupancy, this is likely to be mainly due to occupants turning on equipment and lighting but also timer controls. Gas consumption during warmer periods tends to have a flatter profile though not necessarily at zero consumption as some buildings have gas powered hot water (which seems to be independent of occupancy). Interestingly, there is electricity consumption later into the evening during colder periods. This indicates that the consumption may be due to lighting and that there may be some lighting control based on available natural daylight which decreases in a seasonal pattern closely matching temperature. If the consumption pattern during warmer periods is a proxy for occupancy (i.e. variation above the base-load is the sum of occupants actions) then it may be that lighting in the colder (and presumably darker) evenings is serving very few people.

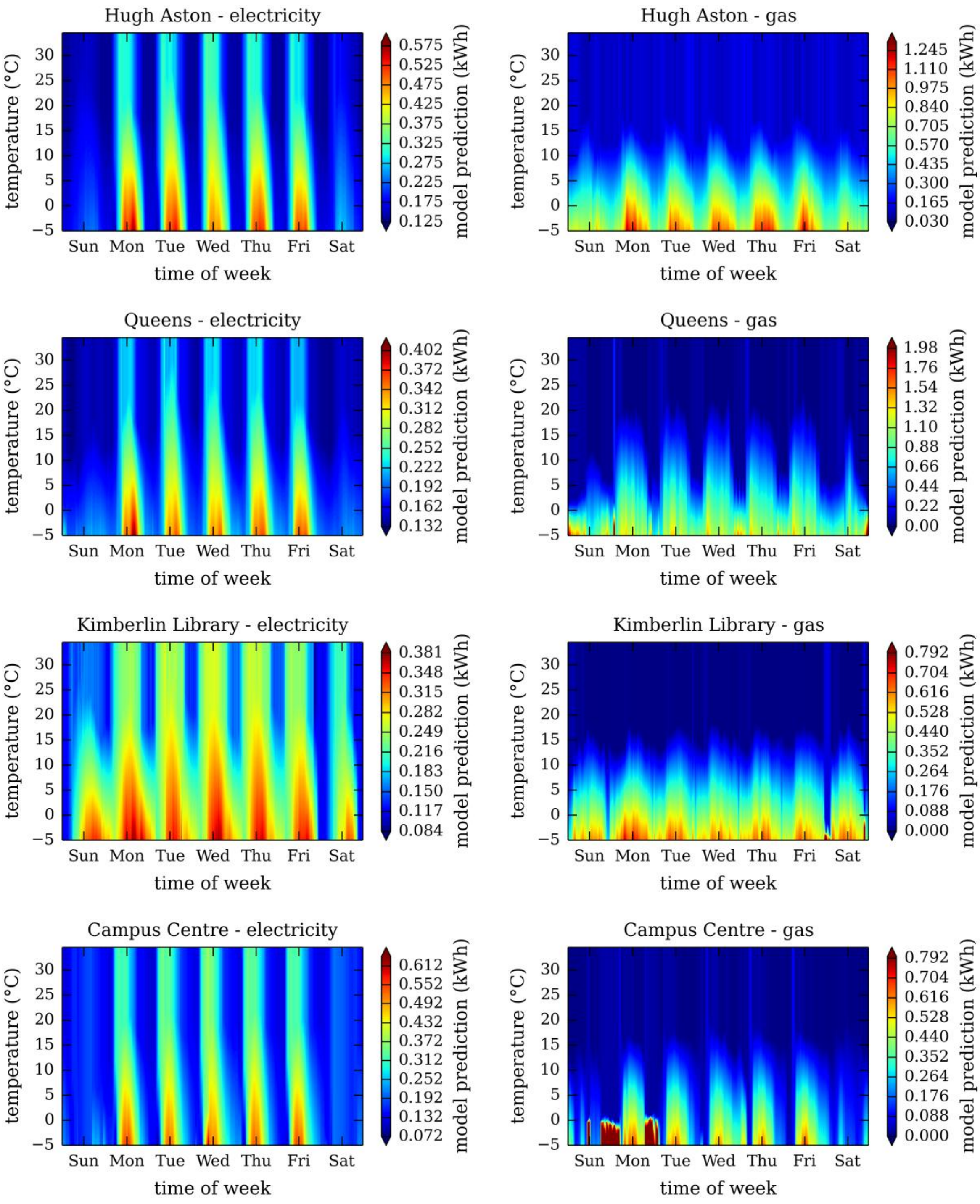

Figure 7: Full consumption models visualised for the example datasets

The model is clearly effective at establishing a realistic pattern of consumption in the baseline period. It is also capable of generating a reliable estimate of consumption under given conditions. This is simply a matter of identifying the time of week and the outside air temperature for which a prediction is required and using the model parameters to produce a predicted value. The following section describes how the model was used.

Setting up a monitoring regime

The model described above can be used to estimate savings using a similar approach to that shown in Figure 4. It can be fitted to 52-weeks of baseline data and used to forecast one or more points into the future using measured outside air temperature and the known time of week for data in the test period. A simplistic approach would then be to directly compare the forecast with the actual measured consumption. This is a very useful approach for calculating savings but requires some interpretation and does not provide a complete picture. The variation in the data around the model (shown for example in Figure 6) is in some cases approaching the scale of consumption being predicted. If this is not communicated as part of the feedback then there is a real danger of misinterpretation. Absolute deviation from the baseline model is not a direct measure of relative energy performance and needs to be presented in context.

For example, in a particular building a deviation of 1kWh during peak occupancy periods may be minor and considered well within the normal variability of consumption. The same deviation of 1kWh may be drastic and noteworthy during unoccupied periods. Similarly, a 1kWh saving may be insignificant in one building but very significant in another. Our aim is to communicate deviation in terms of what is normal for a particular building. As discussed above, it is ultimately desirable to present energy performance as a context-free normalised scale from 'good' to 'bad'. This would then require no special knowledge to interpret the feedback. Such a simple message is likely to be picked up by more users, even those with no experience of the building seeing the feedback for the first time.

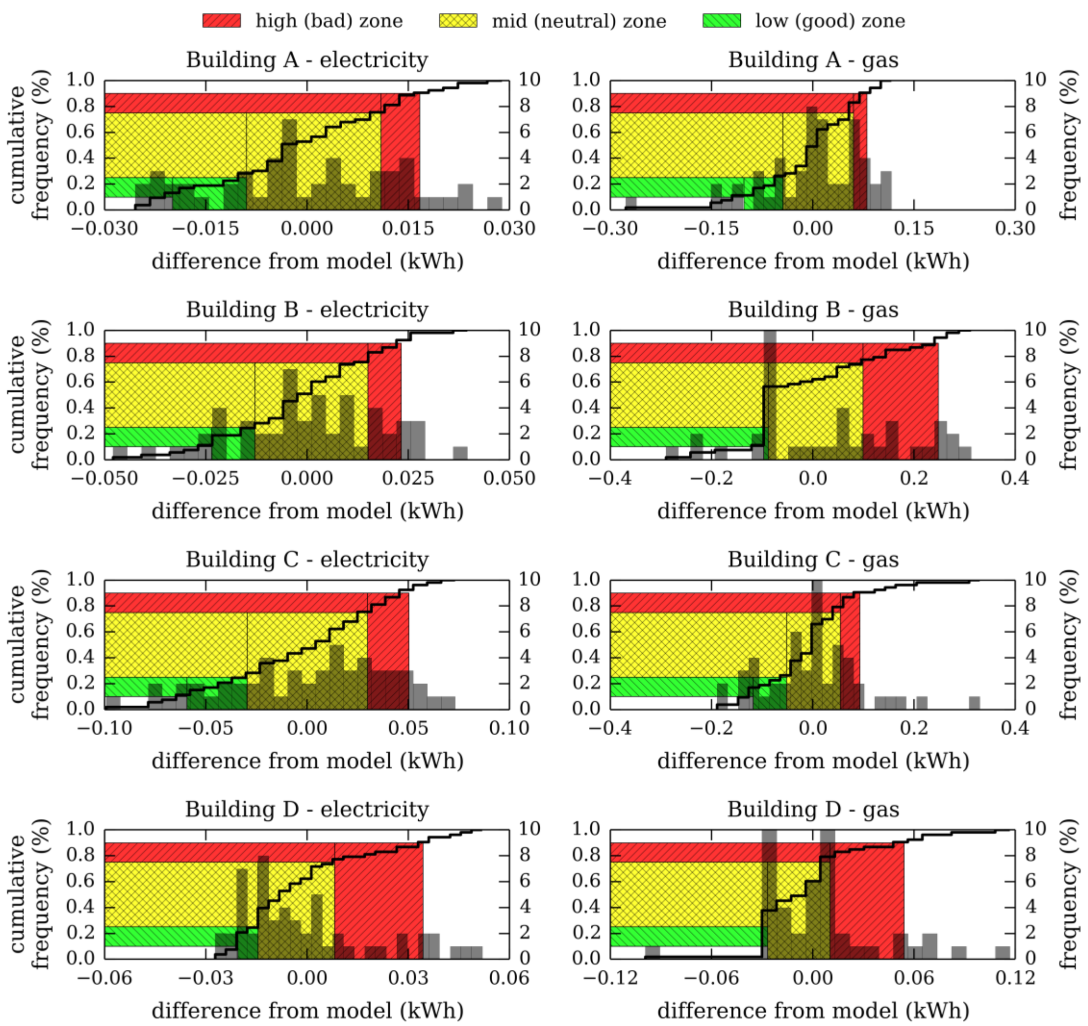

Figure 8: Example sub-model residuals and zones for example datasets (Wed 03:00)

The variability of consumption around the baseline model is seen as scatter in Figure 6. Model residuals are defined as the deviation of consumption from the baseline model prediction for each data point in the baseline period. Model residuals are recorded for each sub-model, Figure 8 shows the residuals for the sub-model fitted to data from 03:00 on Wednesdays. Residuals are presented as both a histogram (grey blocks) and a cumulative histogram (black line). The inter-quartile range and the ranges from 25th – 10th and 75th – 90th percentiles are also highlighted.

A context-free indicator

To calculate our performance indicator, the residual data are used as context for the absolute deviation of the test data point. More specifically, the deviation in the test data is converted into a percentile value within the population of baseline residuals. That is, the proportion of baseline residuals above the test data deviation is determined and this value (which necessarily sits between 0 and 100%) is used as a normalized measure of performance for each half-hourly data point.

The performance indicator can be interpreted as follows. A value of zero implies an extreme negative deviation from the model greater than any experienced in the baseline period. In other words, consumption is further below the model than any of the scatter in Figure 6. A value of 100 implies the opposite case where consumption is further above the model than any of the scatter in Figure 6. A value of 50 implies a non-remarkable deviation from the model, half of the baseline data deviated in a positive direction and half in a negative direction relative to this value. These values are therefore very easily converted into an essentially linear scale from ‘good’ (a value of zero) through ‘neutral‘ (a value of 50) to ‘bad’ (a value of 100).

Visualisation

Direct visualisation of the indicator is described later in this section. First we will consider the construction of various composite visualisations which takes the raw energy consumption data and place it directly in the context provided by the modelling approach described. By providing data in context it is very easy to infer energy performance.

A further way in which baseline model residuals can be used is to compute useful values to provide visual context for the test period data. For example, it is useful to identify the inter-quartile range of the residuals as a 'normal' or 'neutral' range of consumption values. Any consumption in the test period that falls within this range is ‘normal’ in terms of the baseline data. We can also define a 'bad' and a 'good' zone as the 90th - 75th percentile range and 10th - 25th percentile range respectively. To calculate these zones is trivial. The zones are shown in Figure 8 extending from the appropriate cumulative frequency levels (i.e. percentiles on the left y-axis) and mapping to concrete residual values (the x-axis). The mapping is directly related to the cumulative histogram.

These values can then be added back onto the model to produce a predicted range of consumption. The range covers the same percentiles and so will necessarily cover 80% of all consumption data in the baseline period with 10% falling above and 10% falling below. By design, 50% of the baseline data fall in the neutral yellow zone. The zones calculated for the period at 15:00 on Tuesdays are shown in Figure 9 with the original baseline model and data shown for reference. Since the baseline period includes 52 weeks we can expect around 5 points to be located above and 5 points below the highlighted ranges.

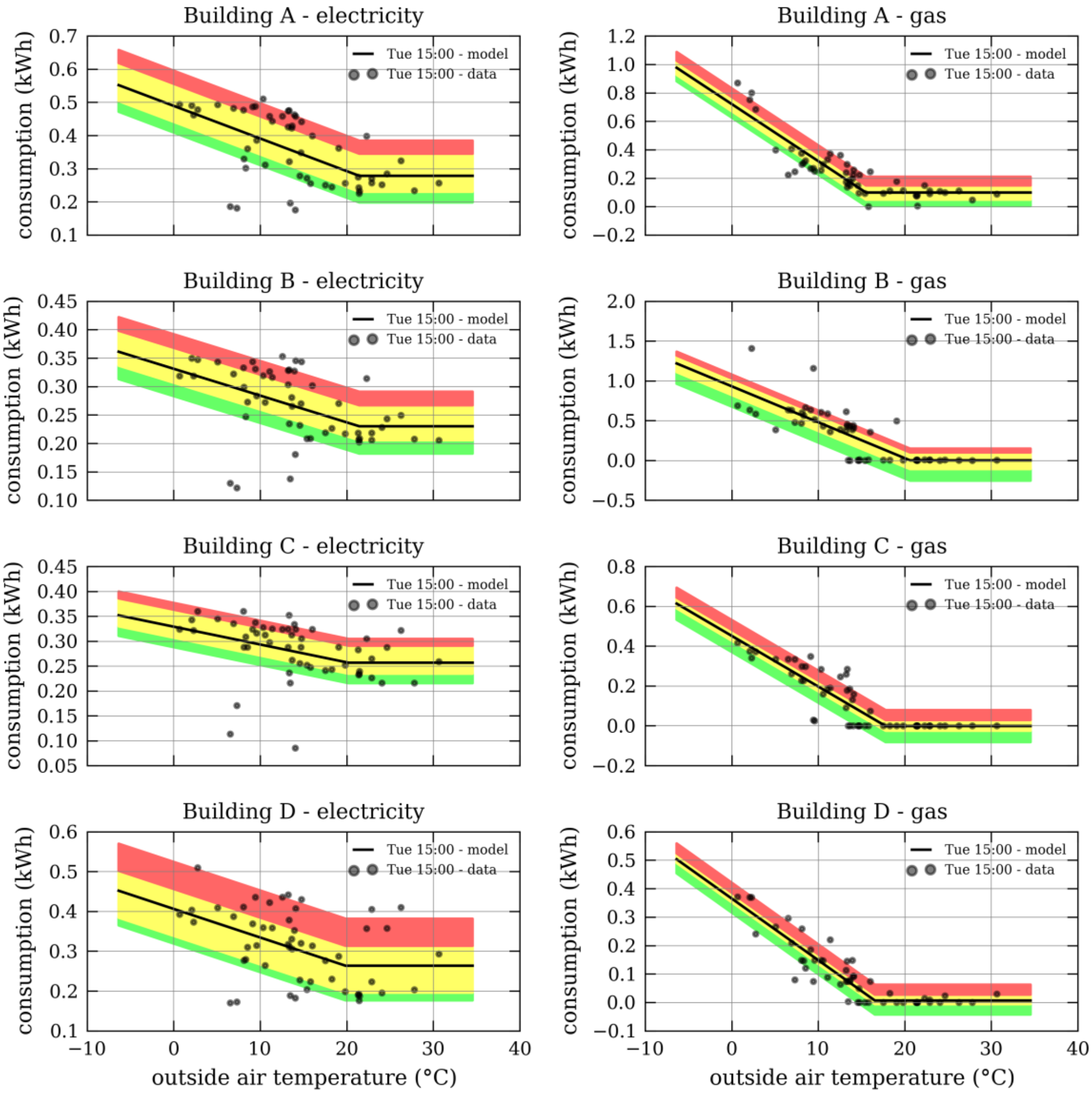

Figure 9: Sub-model (Tue 15:00) with percentile bands included for the example datasets

Taking the first complete week after the baseline (shown in Figure 5) as our test period we can now produce a visualisation which includes this contextual information alongside the actual consumption. It is a simple matter to compute a prediction and to add the calculated ranges. Figure 10 shows the resulting visualisation.

The coloured zones represent the expected range based on data from the baseline period. The raw data can now be easily equated to performance by observing into which of the zones consumption falls. In fact, performance relative to the baseline period can be determined very accurately by observing how deeply the black line falls into the appropriate zone. High values of the indicator are associated with consumption falling deep into the red zone. Low values of the indicator are associated with consumption falling deep into the green zone. Values around 50 fall centrally in the yellow zone.

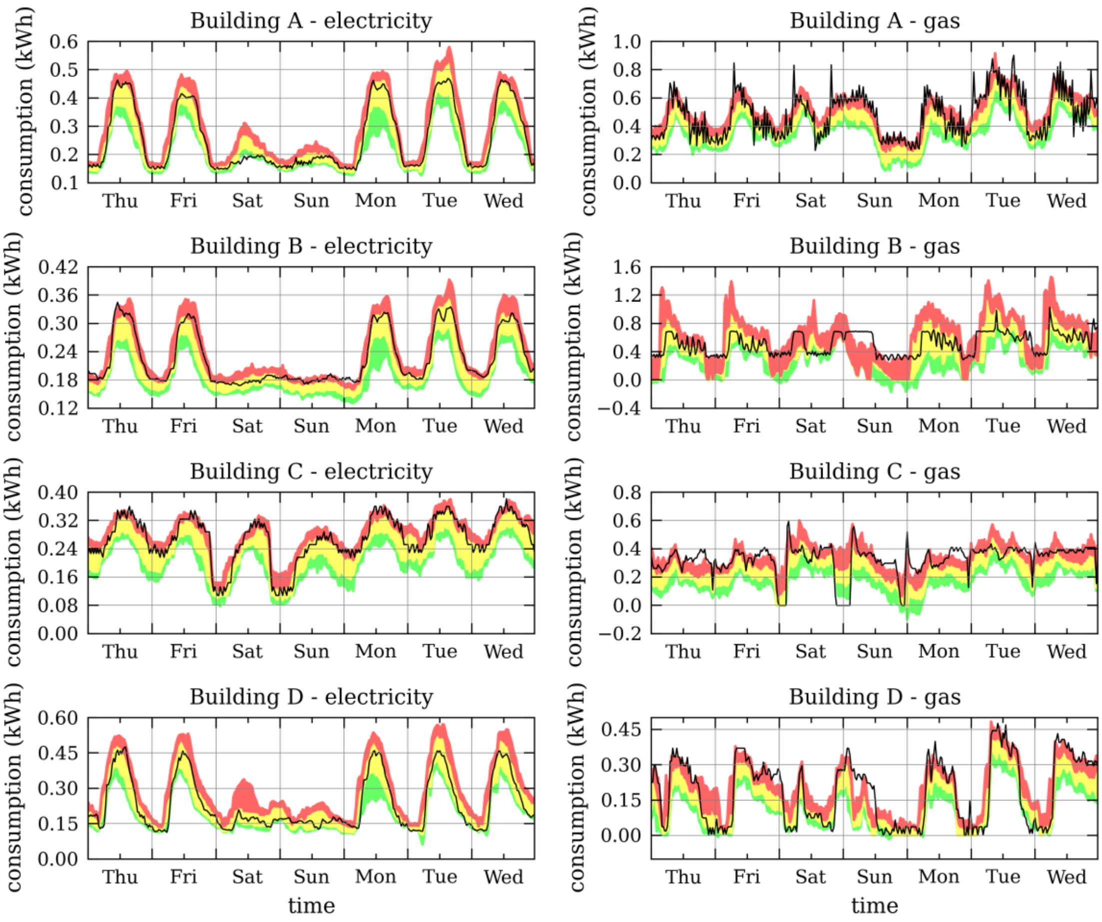

Figure 10: One week period with expected zones calculated from baseline model

This provides a robust visualisation of the model forecast and is an effective way to express the meaning of the indicator. The boundaries between zones from green to red correspond exactly to indicator values of 10, 25, 75 and 90 respectively. Expressing the derivation of the indicator in this way is useful to communicate the nature of the indicator to energy professionals and those building users who want more detail. It also serves as a powerful and intuitive diagnostic tool. Small deviations become very obvious and the predicted effect of outside air temperature is clearly expressed in the modelled zones.

The indicator itself is highly suitable for visualisation in innovative, interesting ways. The indicator is unit-less and ranges linearly from 0 to 100. As such it is possible to map it directly to any set of images representing good, neutral and bad performance. This is a major benefit of the context-free indicator, no special calibration is necessary. It can also be aggregated, for example by averaging to produce values representing daily or weekly periods and it can be compared directly across commodities and even merged across datasets to show overall performance.

Figure 11 includes two example visualisations. The first shows composite visualisation across electricity, gas and water consumption for a single building. The indicator is converted to coloured smiley faces with low values reflected as happy green faces and high values as sad red faces. Intermediate, neutral faces are yellow. The largest face represents an average of the three main indicators. Each of these is an average of 48 values covering the latest 24 hours of available data for the relevant utility. Underneath the main display is a smaller version of the four faces for each of the previous seven days. It is easy to see that performance in all categories has improved over the last week and is still being maintained at a good level. The second visualisation shows a comparison between buildings where the weekly average indicator is used as a more stable measure of overall performance.

Figure 11: Screenshots of example visualisations using aggregated performance indicator

Discussion

The approach described in this paper produces an indicator of energy performance relative to a baseline period. The indicator provides a robust comparison between data in the test period with a model fitted to data from a 365-day baseline period. The indicator ranges from 0 to 100 where zero indicates lower consumption (and presumably, better performance) than any experienced in the baseline period. A value of 100 indicates higher consumption (and presumably poorer performance) than any experienced in the baseline period.

Consumption is compared to the ***baseline model*** and the comparison is made with reference to the scatter around the model produced by the baseline data. This makes the indicator normalized for occupancy patterns and outside air temperature. This normalisation makes the indicator effectively context-free and allows it to be easily interpretable with no special knowledge of the building or the method. This approach also allows the indicator to detect relatively small increases and decreases in consumption against the baseline when the model fits closely to the baseline data.

When implemented in a continuous energy performance feedback system the indicator tracks improvement and deterioration of performance over time. This is ideal for a general purpose, objective energy performance feedback system. A simple monitoring scheme would create a baseline model with the first 12-months of available data and use this model to compute an indicator for one time-step. The next time-step would be calculated using a baseline model fitted to the 12-month period ending on the previous time-step and this would roll forwards one time-step at a time.

In practice this is computationally expensive. The computational requirements can be reduced by rolling the baseline one week at a time. Far fewer model fitting operations are conducted by using a single baseline model instance fitted to 12 months of historical data to forecast values for a full week of consumption. This way each week, rather than each half-hour of consumption has its own baseline model and the effectiveness of the scheme is not affected.

The indicator is designed to be sensitive to changes in building base load (the minimum consumption during unoccupied periods). By considering each 'time of week' independently it is possible to identify the variation in the base-load (which is often quite small) and so any reductions or increases in the base load are identified easily. The base load is often responsible for a large proportion of total consumption. Base load consumption occurs 24 hours a day and so a 1kW reduction in these loads represents a greater saving than a similar reduction in occupancy-related loads. A problem identified during unoccupied periods may indicate an opportunity to reduce the baseline.

The indicator provides a very convenient index for visualisation. A normalised value which is guaranteed to fall between 0 and 100 can easily be transformed onto any visual scale, in particular user-friendly scales which indicate good, neutral or bad performance. Examples of these include common metaphors such as traffic lights, thumbs up or down and smiley faces. It can also be aggregated over time by taking a simple average of multiple indicators.

For example the Leicester smartspaces pilot system [5] employs smiley faces to communicate the value of the indicator to building users on public screens within the building. Figure 11 shows a screenshot from the system. The electricity, gas and water performance indicators are averaged together to produce an overall figure. The screenshot also indicates the average of the latest 24 hours of indicators and seven figures for seven complete days. The half-hourly performance indicator allows user interface designers great flexibility in what can be presented by simply aggregating indicators over time and across datasets.

The system also has the benefit of being entirely objective. There are no special targets set, the indicator can be calculated for any building that responds well to modeling in the way described. In principal it would be possible to apply the same methodology and fitting the baseline data to any suitable consumption model. The indicator will always respond in the same way, providing a measure of improvement or deterioration.

It is important to recognize trust issues in a feedback system. Simply presenting smiley faces without providing a path back to the baseline model and raw data could erode trust in the system. Providing more detailed visualisations such as shown in Figure 8, Figure 9 and Figure 10 ensures transparency and can help more enthusiastic users understand their building in greater detail. To provide this as part of a user interface it is desirable to start with high-level interpretation (e.g. smiley faces representing a week) and drill deeper with each click, eventually reaching the most complex visualisations.

A great benefit of the approach is that it can be implemented with minimal input data, commonly available via AMR or smart meters. The example datasets include half-hourly energy consumption data (gas and electricity, although the approach has also been used with water data) and outside air temperature (also half-hourly). With these data and appropriately configured software it is possible to implement a complete system.

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Building end-uses approach for electrical consumption forecasting

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Abstract

The calculation of electricity consumption forecast a few days ahead is a complex issue and studies about this matter are continually being performed. Advances in this field enable obtaining consumption forecasts increasingly accurate. These consumption forecasts aim to improve the knowledge of the facilities, the planning and control of consumption and the measurement and verification of energy saving measures, among others. In this study the authors present several advances related to consumption forecast using end-use (EU) approach. In the disaggregation of the total consumption process, the correlation between energy and external variables, such as mean temperature, degree days or daylight, is studied. Additionally, an extrapolation method to obtain a total consumption forecast from forecasted EUs consumption that cover approximately 60% of total consumption is developed. With this procedure, total consumption forecasts with high accuracy can be obtained. The higher accuracy in each end-use, the better results are obtained in the total consumption forecast. For this reason, the study is focused in the end-uses disaggregation and its forecast calculation. The entire methodology is illustrated and contrasted using the consumption of the Universitat Politècnica de València (UPV).

1. Introduction

The energy consumption may be related to the search different benefits. However, quantifying the benefit provided by consuming a certain amount of energy is often difficult. The best way to do this is to divide the consumption into end-uses (EUs) or processes to assign a benefit to each kWh of each process. This will also enable estimating the advantage of achieving a certain energy saving on an EU more accurately. Accurate consumption forecasts are important to measurement and verification as well as to participate in the demand response programs, as it has been previously discussed in other publications of the authors [1-4]. To sum up, each consumption fraction can be dependent on different external variables and these fractions are what are called EUs.

The consumption of a building or a large and complex facility can be divided, according to this criterion, into different EUs. For each EU, the forecasting process should consist of two phases. The first phase is the process of selecting the most similar days to the day of prevision (DOP). I.e., to find days in which external variables that affect the EU consumption have similar values to the DOP. The second phase is the forecasting calculus. This phase can be accomplished in many different ways. In previous study made by the authors, artificial neural networks to calculate the forecast were used. In this study the selection process is improved and a much easier and faster forecast method that achieves accurate results is developed. This method calculates a forecast for each EU and the total consumption for each hour of the day using the conditions of the DOP and the conditions and consumption of selected days.

As previously discussed in other papers of the authors, the number of selected days must be reduced, 4 days were used [1, 2]. So 4 days must be selected for each EU in which the variables that affect the consumption are as close as possible to the DOP.

The division of the total consumption into the different EUs provides several advantages, such as making different fractions of the consumption independent on the external variables that do not affect them. It also enables greater control and understanding of how energy is consumed. In addition, it simplifies the process of purchasing energy in the spot markets [5]. Furthermore, some applications oriented to specific EUs such as measurement and verification of energy efficiency and energy management actions applied on different EUs are enabled [6-8]. In conclusion, the decomposition of consumption into EUs helps the consumption forecast step in the sense that it enables the use of different input variables for the prediction of each EU, providing a series of additional benefits already discussed. A possible EUs classification is analyzed below.

The paper is organised as follows. Section 2 explains the whole methodology, introducing the necessary concepts and showing the information available related to EUs. Section 3 describes the classification of the end-used performed in this study. Section 4 explains the consumption forecast phase and the extrapolation of the EUs consumption in order to calculate the total consumption forecast for the facility. Section 5 shows the results of applying the methodology to the consumption forecast of the Universitat Politècnica de València (UPV). Finally, in Section 6 some conclusions are drawn.

2. Methodology

The proposed methodology to carry out the forecast consumption of a facility consists of two phases. The first phase is the selection of days similar to the DOP. The second stage is the consumption forecast phase.

To carry out the day selection, a thorough analysis of the EUs of the facility is first performed. All variables that influence the consumption profile of each EU are analysed. Then, individual weights are assigned to each variable that affects the consumption of each EU. This will establish how each criterion affects each EU. This is necessary in order to decide which days are more similar to the DOP. The process consists of assigning qualifications to each criterion of each day depending on the similarity of each variable with the value it has for the DOP. Then, using the weights assigned to the criteria, a mark is given to each day calculated as a weighted average of the criteria qualifications. This enables ordering the days by a mark to carry out the selection of four days among those which obtained the highest mark. All the days whose consumption or whose variables are considered anomalous must be removed before the days selection is made.

The criteria to be considered are external variables that affect consumption. For each EU a unique relationship between consumption and external variables can be studied. That is the reason why the study of this relationship must be first done and different weights must be assigned to each criterion for each EU. There is a common criterion to all EUs, proximity to the DOP. It has been proven over time the need to choose days surrounding the DOP to calculate an accurate consumption forecast, so this criterion must always have a significant weight.

To carry out the prevision of EUs, the heuristic method (average of 4 similar days) described in [1] is used. Finally, an algorithm to obtain the total consumption forecast using the EUs consumption on selected days and the EUs forecast previously obtained for the DOP is applied. This algorithm performs a linear interpolation (or extrapolation if applicable) to obtain the total consumption forecast of the DOP.

The entire forecasting process is outlined in Figure 1.

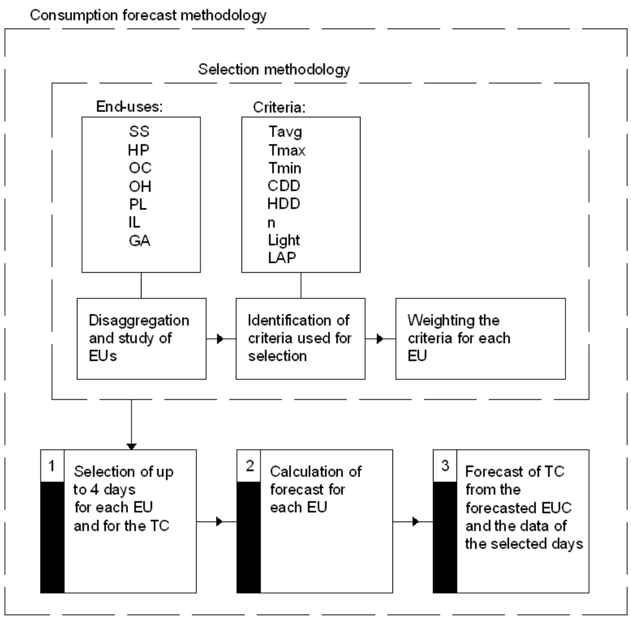


Figure 1. General diagram of the consumption forecast mehtod.

The average temperature (Tavg), the Cooling Degree Days (CDD), the Heating Degree Days (HDD), the maximum temperature (Tmax), minimum temperature (Tmin), the proximity to the DOP (n), the light factor (Light), a parameter that quantifies the need for artificial light of a day from its cloudiness are the variables used in this study that consumption depend on and the labour activity parameter (LAP) used to represent the activity of each type of day (weekdays, weekend, holidays, etc.) [1].

Table 1 shows the number of measuring points that make up each EU and the main external variable that affects the consumption of each EU.

Table 1. Measuring points of EUs.

EU	Description	Number of measuring points	Main external variable that depends
SS	Split systems consumption	25	Tª
HP	Heat pumps consumption	36	Tª
OC	Only cold production	2	Tª
OH	Only heat production	4	Tª
PL	Public lighting	15	Day number
IL	Internal lighting	18	External light
GA	General appliances	16	Occupancy
TC	Total consumption	1	All

The UPV has an Energy Management and Control System (EMCS) which has a total of 300 measuring points distributed along its 90 buildings. With these measuring points, consumption is measured every fifteen minutes and it is stored in a database since 2005. To classify the EUs of these facilities some of these measuring points have been classified into groups according to the type of loads fed and the behaviour in relation to external variables. Therefore, the EUs consumption curves in the UPV are the result of adding a large amount of consumption measuring points, providing a reasonably high stability to the daily consumption of each EU.

The consumption formed by the addition of the identified EUs is what is called the end-uses consumption (EUC), which represents around 60% of the UPV's total consumption (TC). This percentage is being constantly revised and improved by identifying and classifying the type of consumption measured by new measurement points installed in the UPV. An accurate prediction of the EUC results in a good prediction of the TC simply by using a fast and easy extrapolation method explained below. Therefore, it is important to improve the selection and classification of EUs so as to get a reliable and strict relationship between consumption and external variables. This will permit finding a good days selection, similar to the DOP, in both the input variables and consumption for each EU, improving the forecast accuracy.

3. End-uses study

First, the temperature-dependent consumption end-uses are classified into four groups, the consumption that has a unique behaviour for all seasons, Split Systems end-use (SS) . This is because this EU includes machines whose operation mode is automatically selected depending on the desired temperature and the external temperature. Secondly, processes with seasonal behaviour, such as heat pumps (HP), which operate differently depending on whether they are in heating or cooling mode and that mode switching occurs manually at a certain moment of the year. Different from the previous ones are those machines that produce cold at any time of year, the only chillers systems (OC). Thus, this is a refrigeration consumption, which is only affected by high temperatures, but for low values this consumption remains at a small value (residual consumption). Finally, the last temperature-dependent consumption is the consumption of radiators, heaters, etc., that is the only heat systems (OH). This type of process is always producing heat, so it is only affected by temperatures lower than a certain value, and above this thermal limit the consumption of this EU is a low consumption.

Besides temperature-dependent EUs, there are other EUs, such us lighting consumption that can be separated in public lighting (PL), which is dependent on the length of the daylight hours and the interior lighting (IL), which depends on the cloudiness and the time of the day.

Finally, another EU which mainly depends on the facilities occupancy is the identified as general appliances (GA) end-use.

The behaviour of each EU in relation to different variables which affects its consumption is analysed below. The relationship between daily energy consumption of each end-use and different external variables is studied considering the day of the week for those EUs that have a dependency on the working patterns. All the days are considered if consumption does not depend on working patterns. This relationship has been studied in detail to produce the table of weights of the criteria used for selecting the days similar to the DOP. Every day whose behaviour is anomalous for any reason (measurement errors, specific events, reduced work time, etc.) has been removed in this study. The energy has been normalized to the energy value of the 25% percentile of the consumption of the considered days.

3.1 Split systems end-use (SS)

Figure 2 shows the relationship between the daily energy of the SS and the average temperature of the day, for weekdays (Tuesday, Wednesday and Thursday).

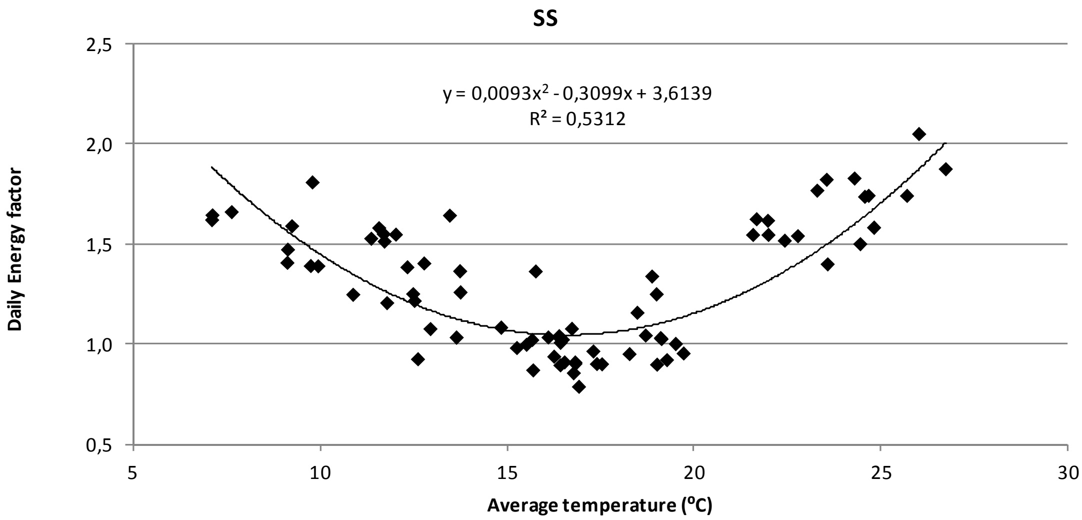


Figure 2. Relationship between the daily energy and the average temperature for weekdays for the SS.

It can be seen that at low and high temperatures there is a higher consumption, with a saturation value determined by the power of the equipment, its performance and the acclimatization conditions of the facility. In this case, the average temperature has a great importance, as well as the CDD (or the HDD according to the trend of the DOP) to establish a correlation with the consumption. All this is reflected in the weights assigned to each criterion for this EU.

3.2 Heat pumps end-use (HP)

HP is composed of heat pumps and air conditioning machines with manual mode switch is studied below. Figure 3 shows the correlation between the HP and the average temperature of the day.

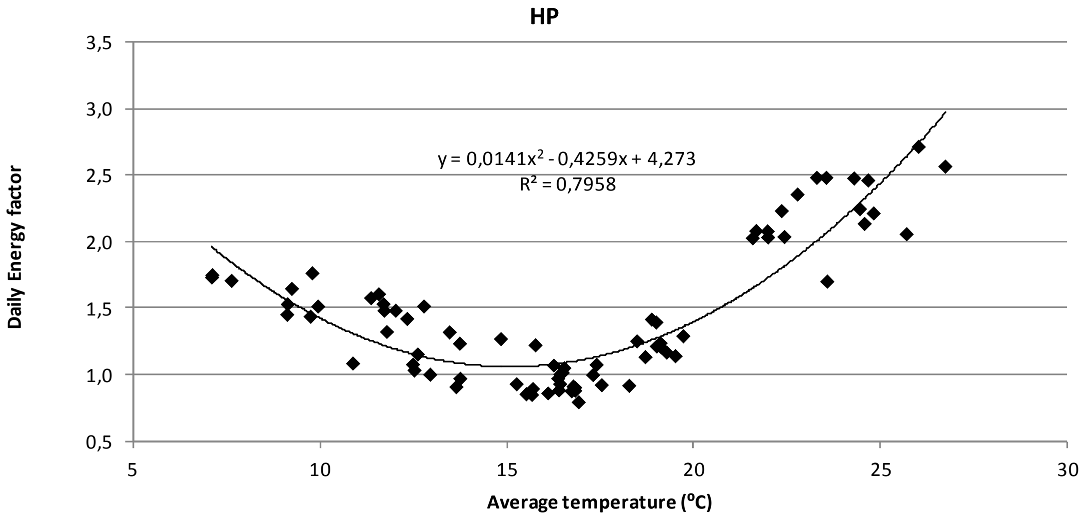
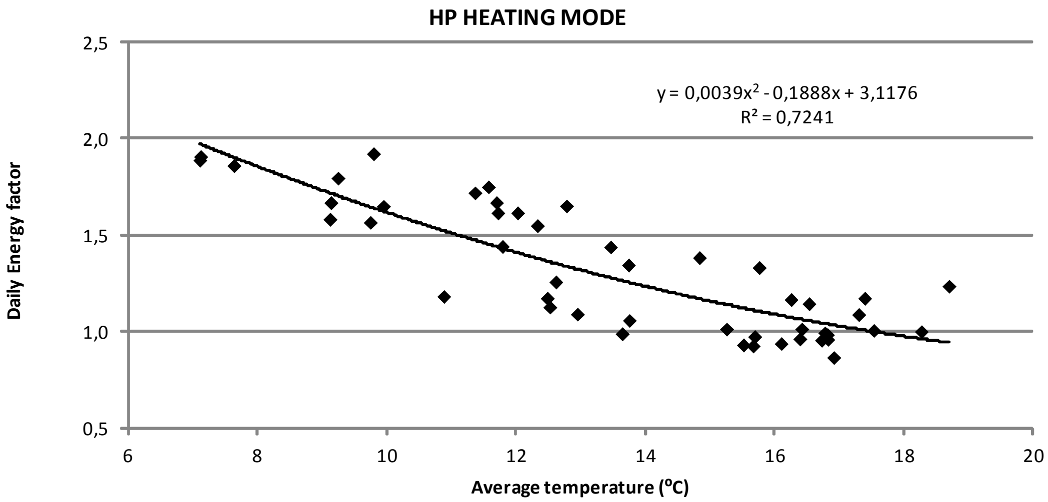


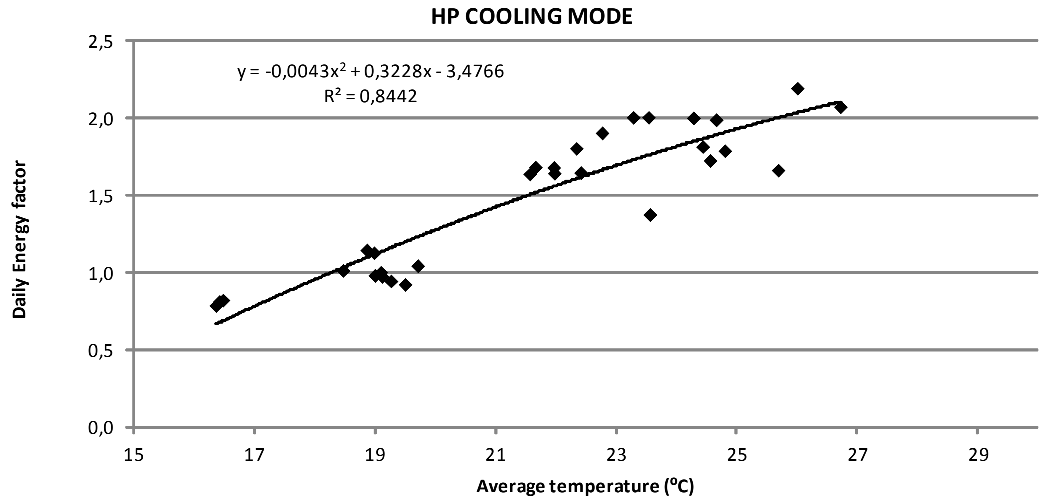
Figure 3. Correlation between the daily energy consumption and the average temperature for the HP.

In this EU there is a fairly good correlation, which is an important advantage of the disaggregation, since some consumption fractions are identified with a great accuracy correlation with certain input variables. However, due to the manual operation mode switch, there are two different correlations that can be separated to improve the forecast results. These correlations must be done by separating the days in which the machines operate in heating mode and the days in which they operate in cooling mode. This permits having two curves, one showing a tendency to increase at low temperatures and another one that increases at high temperatures. Figure 4 shows these two correlations.

As clearly seen, the behaviour of these machines in cooling mode is much more related to the average temperature of the day than the opposite behaviour. Therefore, due to the difference between these correlations, using days with the same operating mode than the DOP is always needed to calculate an accurate consumption forecast for this EU. Indeed, the behaviour of this EU is similar to previous one, thus, the weights are also similar, although there is slight increase in the weight of the average temperature while the maximum and minimum temperature weights are reduced.



(a)



(b)

Figure 4. Correlation between the daily energy consumption and the average temperature for HP in heating mode (a) and in cooling mode (b).

3.3 Only cold end-use (OC)

This EU includes machines producing cold at any season of the year. In this case, Figure 5 shows that there is a high correlation between the average temperature of the day and the consumption of this EU. It can be noted that below a certain temperature the consumption remains practically constant.

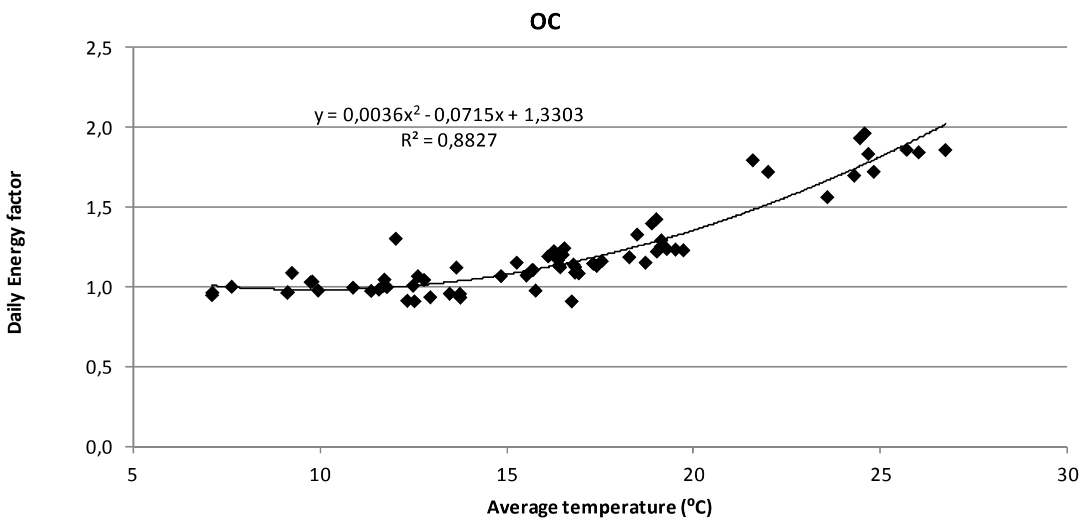


Figure 5. Correlation between the daily energy consumption and the average temperature for OC.

3.4 Only heat end-use (OH)

The OH presents the behaviour shown in Figure 6.

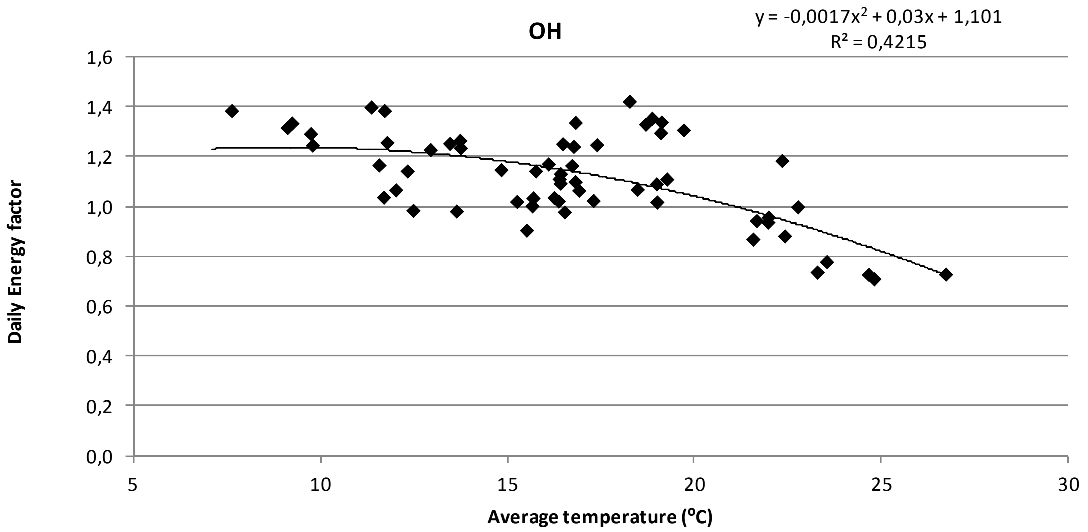


Figure 6. Correlation between the daily energy consumption and the average temperature for OH.

It can be seen that the average temperature is much more related to the consumption of cold production machines than with the heat production consumption. The OH presents a rather erratic behaviour, which leads to the need to ensure the use of days close to the DOP to minimize the error in the forecasts by taking close and presumably similar conditions. The weight assigned to the thermal variables is considerably reduced as a result of the study carried out for this EU.

3.5 Public light end-use (PL)

The other EUs that are not temperature-dependent can be correlated with the day number of the year, since these EUs usually has a smooth evolution along the time. Thus, the resemblance between the consumption of a certain day and those around it can be noted. In the case of public lighting, the consumption is not dependent on the working patterns. The only variable that affects this EU is the duration of the night (or equivalently the daylight length). In this EU, light turns on automatically when daylight falls below 100 lux as PLCs used to control lighting lines have been programmed. The following graph shows a whole year evolution for this EU.

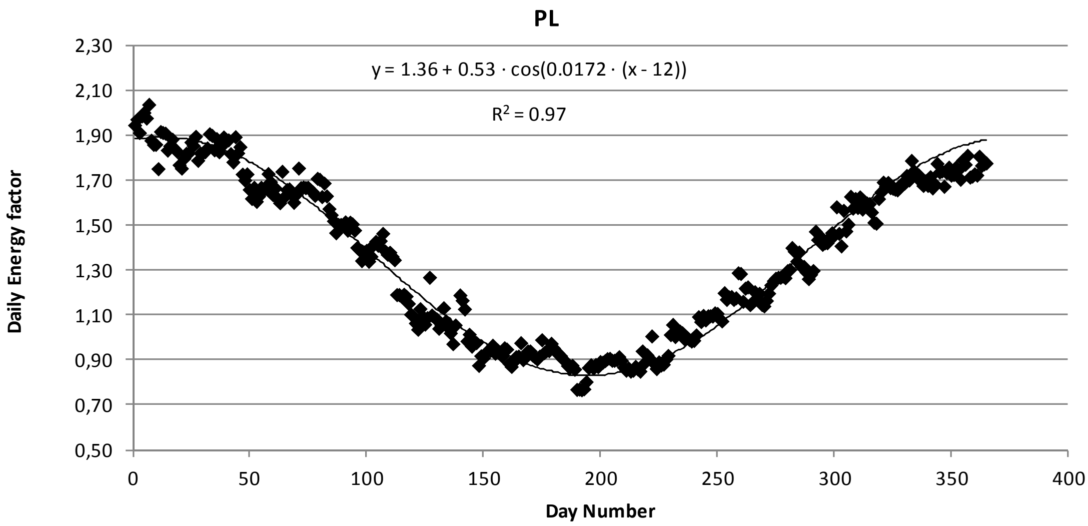


Figure 7. Consumption evolution for PL.

The behaviour of this EU is sinusoidal, like the evolution of the daylight hours throughout the year. Therefore, in this EU, the only criterion that is considered is the day of the year, since the consumption is very similar for consecutive days.

3.6 Internal lighting end-use (IL)

The internal lighting is similar to public lighting, but it has two important differences: it is affected by the working patterns and the consumption is high when a day is very cloudy, but is fairly constant on clear days. Figure 8 shows the behaviour of this EU.

The days show an evolution with a slight sinusoidal tendency in which each day consumes similarly to those around it. In this graph, the dependence of the consumption of this EU on natural light can be seen, since the four days with the higher cloudiness have been marked and they have interpolated with a sine curve higher than curve used to interpolate the other days of the year.

It is therefore important to choose a cloudy day if the DOP is cloudy. Otherwise, it will be needed to use the days closest to the DOP with the same LAP.

To take into account the cloudiness of a day, the daylight factor (DLF) is defined. This factor is a value calculated from (1). The DLF represents the need of artificial light depending on the measurement of radiation throughout the day. Therefore, the cloudiness of a day is defined as a value from 0 (clear) to 4,000 (totally cloudy). This value is 4000 minus the average of all values below 4.000 lux during the day from 9 am to 5 pm.

$$\mathrm{DLF} = \begin{cases} 4{,}000 - \left(\mathrm{avg}(\mathrm{lux_i})_{\forall \mathrm{lux_i}<4{,}000}\right) & , \exists \mathrm{i} \mid \mathrm{lux_i} < 4{,}000 \\ 0 & \mathrm{lux_i} \geq 4{,}000 \forall \mathrm{i} \end{cases} \tag{1}$$

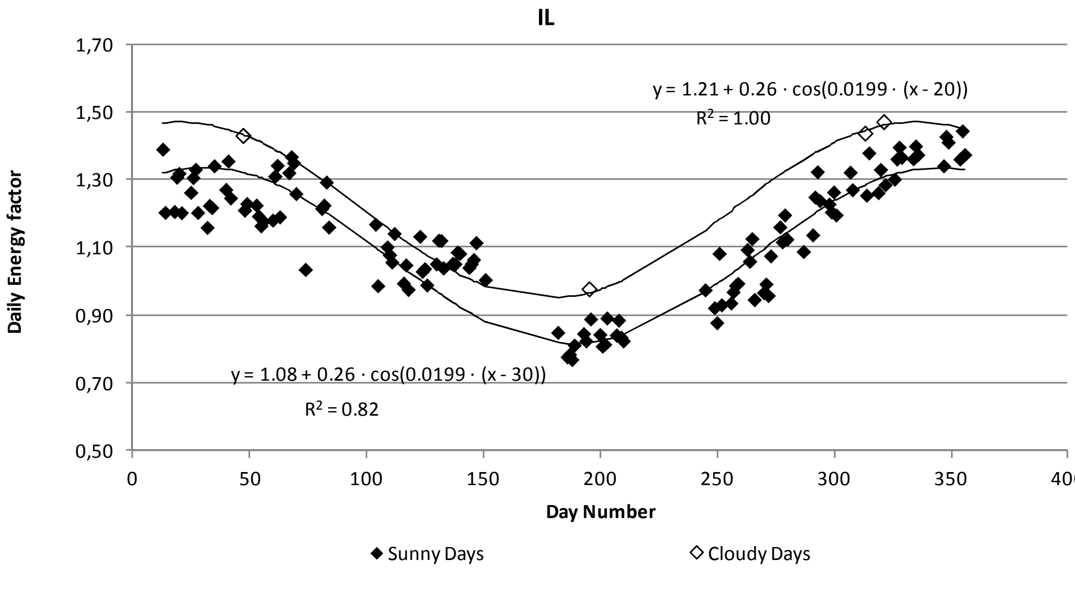


Figure 8. Consumption evolution for IL in cloudy and sunny days.

In this study, lux values, were recorded every 5-15 minutes in order to obtain a good accuracy in the calculation of the DLF.

3.7 General appliances end-use (GA)

Finally, the consumption of the general appliances depends on the occupancy of the facilities. In this consumption that exist only when staff is present on site, the most important variable to select a day is the LAP and must be chosen as close as possible to the DOP. In Figure 9 this EU is analysed.

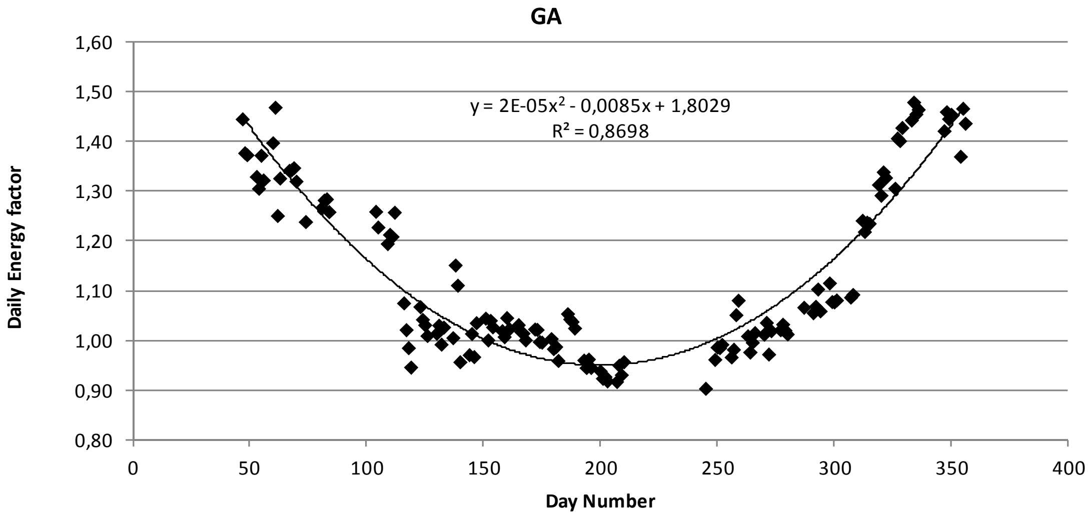


Figure 9. Consumption evolution for GA.

As can be seen in Figure 9, this EU presents high correlation. Although, there may be isolated some consumption points with anomalous behaviour. The best option to prevent this variability from producing a significant influence in the forecast is not to use these anomalous days for future forecasts after identifying that the consumption of these days is unjustified. Moreover it is appreciated that the days surrounding a certain area usually have a similar consumption. Therefore, four days will be selected from the available days closest to the DOP to calculate a rigorous forecast of this EU.

4. Consumption forecast method

The criteria used to carry out the days selection has a different influence on the consumption of each EU. Due to this fact, different weights are assigned to each criterion for each EU in order to qualify dates from historical data when carrying out the selection of the most appropriate days. This is the result of the previous study of EUs.

As a result of the analysis of the different end-uses, weights are assigned to each variable for each EU in order to qualify dates from historical data when carrying out the selection of the most appropriate training days in the forecasting method. The weights presented in the table are the result of the presented study of the end-uses. All the information related to the weights of the criteria, quantified according to this study is shown in Table 2.

Table 2. Weights for each EU and TC.

	T_{avg} (°C)	CDD	HDD	n (day number)	Light	T_{max} (°C)	T_{min} (°C)	LAP
SS	1.95	1.30	0.26	3.90	0.00	1.95	0.65	Yes
HP	2.63	1.89	0.21	3.16	0.00	1.58	0.53	Yes
OC	1.50	0.50	0.00	6.00	0.00	1.00	1.00	Yes
OH	0.52	0.00	0.61	8.70	0.00	0.13	0.04	Yes
PL	0.00	0.00	0.00	10.00	0.00	0.00	0.00	No
IL	0.00	0.00	0.00	0.91	9.09	0.00	0.00	Yes
GA	0.00	0.00	0.00	10.00	0.00	0.00	0.00	Yes
TC	2.16	0.43	0.07	4.32	0.14	2.16	0.72	Yes

Note that when the weights assigned to CDD and HDD are not null for an EU these values are the ones showed in the table assuming that in the DOP CDD>HDD (it is a hot day). Otherwise, the weights should be exchanged, and if the values of CDD and HDD were very similar (e.g. |CDD-HDD|<10), then each weight should be the average of both values (the weights would be divided into two equal parts).

The total consumption (TC in Table 2) is regarded as a combination of the different EU, therefore the weights have been assigned as a combination of the weights of the different end-uses.

As commented previously, the LAP can influence the consumption of a day. A LAP value is defined for each historical day and also for the DOP. An additional labour affinity table is created to assign a labour factor $\mathrm{Lab}_{\mathrm{factor}}$ to each pair of LAP values. $\mathrm{Lab}_{\mathrm{factor}}$ is a value between 0 and 1 to indicate the affinity between these two values of LAP. Thus, $\mathrm{Lab}_{\mathrm{factor}}$ value of 0 implies that these LAP values are very different and an affinity value of 1 means that both LAP values are considered identical. Intermediate values quantify the similarity between the two LAP values. The mark obtained by each day is multiplied by the $\mathrm{Lab}_{\mathrm{factor}}$ between the LAP of that day and the LAP of the DOP. This step can penalize or even cancel the mark of days with a working pattern different to DOP. This is performed whenever the EU consumption is affected by LAP, thereby correcting the notes assigned to each day. As a result of this step, only days with the same working patterns as the DOP will be selected. If there are no days with the same LAP, then the days with the most similar LAP values will be selected.

Thus, in each EU, the selection of the four days more similar to the DOP is carried out by assigning a mark to each day and choosing the top four. These marks are calculated as the weighted average of the notes on each of the criteria. That is, for each end use, the obtained mark using expression (2).

$$M_i = \left(\sum_{j=1}^{N_{criteria}} M_{i,j} \cdot W_j \right) \cdot Lab_{factor} \qquad (2)$$

Where i represents each of the possible days to be selected, j is each of the criteria; Ncriteria is the total number of criteria (7 in this study); Mi, j is the mark from 0 to 1 obtained by the day i in the criterion j, it can be 1 if the day is identical to the DOP for this criterion or 0 if this criterion is the least similar among all the possible days, and it may be any intermediate decimal value; Wj is the weight of the criterion j for the current EU, that is shown in Table 2.

The extrapolation method that has been developed is based on linear interpolation and extrapolation with constant limits. To carry out the calculation of TC for a specific instant the EUC at that moment for the four selected days and the expected EUC for the DOP at that moment are used. Among the four chosen values only the two nearest to the expected value for the DOP are used, one above and one below (EUC_1, EUC_2). If it is not possible to select a value above and one below, the closest values will be used.

With these two values of EUC and the expected TC values for that moment (TC_1, TC_2), a line is drawn to perform the extrapolation (if needed) allowing 15% above and below the value of maximum and minimum TC. Once these limits are reached, two horizontal lines are used to continue the extrapolation function. This dashed function will result in the value of the forecasted TC for the DOP at the given time from the forecast of EUC for the same moment. Figure 10 shows the extrapolation process described above.

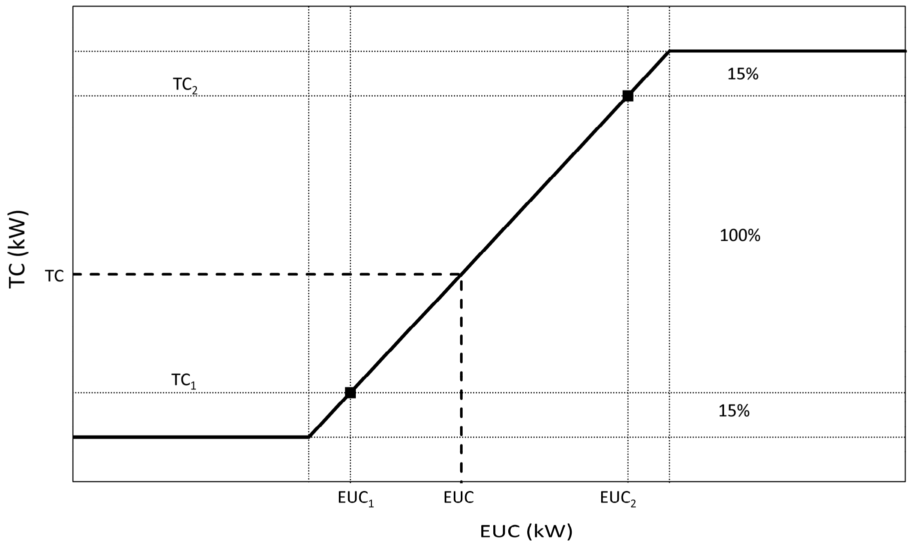


Figure 10. Function used to calculate the extrapolation of the TC from the forecasted EUC for each moment of the DOP.

As shown, this is a simplification of a sigmoid function. This function provides linear values in the intermediate zone and it avoids excessively high extrapolations.

5. Application and results

The composition of EU in the UPV is shown below. It can be seen that the greater part of them is represented by thermal EUs (Figure 11).

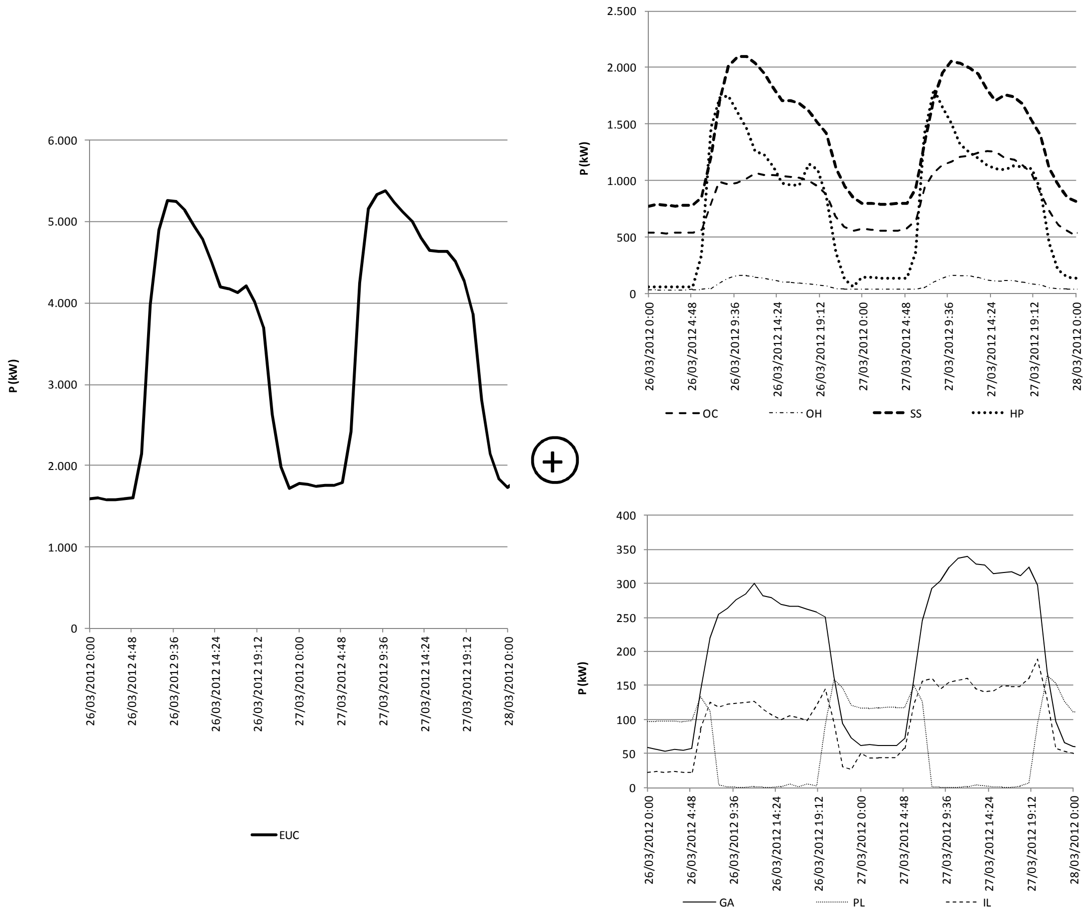


Figure 11. Composition of the addition of EUs from thermal and non-thermal EUs in the UPV.

The forecast for each EU is obtained using the described methodology with the appropriate weights of the criteria to select days and applying the heuristic method to perform the calculation of the forecast, commented in section 2.

The sum of all EUs curves results in the EUC curve. This EUC forecasted curve is extrapolated to obtain the TC forecasted curve for the facility.

Figure 12 shows the forecasted consumption of a full week for TC and EUC in the UPV. It can be seen how the errors obtained in the EUC forecast are translated into similar errors in the TC curve. From another point of view, the accuracy achieved in the calculation of the EUC forecast remains at the same level in the TC forecast.

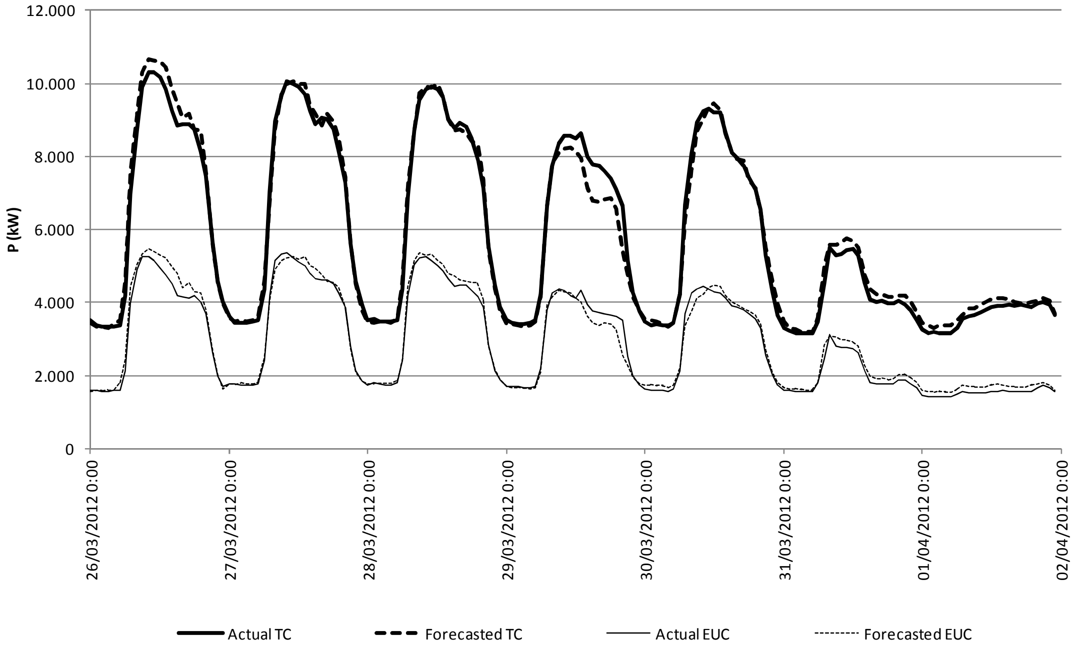


Figure 12. TC and EUC forecasts for a whole week in the UPV.

In the previous figure, the curves "Actual EUC" and "Actual TC" are the actual consumption curves for EUs and TC of the facility and the curves called "Forecasted EUC" and "Forecasted TC" are the forecasted curves for EUC and TC respectively.

The results for this week have an average MAPE of 3.39%. The individual MAPE for each day are shown in Table 3.

$$\mathrm{MAPE} = \frac{1}{N}\sum_{t=1}^{N}\frac{\left|\hat{L}_t - L_t\right|}{L_t}\times 100 \qquad (3)$$

Table 3. MAPE values obtained in the forecasts made for the week from 2012/3/26 to 2012/4/1.

Date	3/26/2012	3/27/2012	3/28/2012	3/29/2012	3/30/2012	3/31/2012	4/1/2012	Avg
MAPE	3.38%	1.97%	1.68%	5.32%	2.33%	4.63%	4.44%	3.39%

Over a whole year (from July 2011 to June 2012), the results obtained with this methodology have an average MAPE of 5.15%.

6. Conclusions

A new methodology has been proposed for electrical consumption forecasting using end-uses decomposition.

Behaviour of different end-uses has been identified and enables an optimal selection of similar days to the day of prediction for using in the forecast method.

The number of selected days (4 days) for each end-use must be reduced and close to the day of prediction in which the variables that affect the electrical consumption are similar to the day of prediction.

The described methodology has a high accuracy in the total consumption forecast, using a simple heuristic method, and it enables the calculation of the total consumption from a previously calculated forecast of the end-use consumption that represents about 60% of the total consumption.

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Study on the Database for Energy Consumption of Commercial Buildings (DECC)

Part 2: Building Energy Consumption in Japan before and after the Great East Japan Earthquake

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Abstract

The Great East Japan Earthquake occurred on March 11, 2011. Within several hours after the earthquake, the Fukushima nuclear crisis occurred and several thermal electric power plants were damaged [1]. The Government of Japan invoked the restriction of electricity use for the first time since 1974 in order to avoid unplanned power outages in the summer of 2011. Furthermore, the situation of power supply shortage spread over not only Kanto and Tohoku but also other regions by the summer of 2011 because of the suspension of the operation of other nuclear power plants. As a result, measures for electricity conservation especially at peak time on weekdays were implemented over almost all parts of Japan. The DECC Committee conducted an investigation on the energy consumption of commercial buildings across Japan for a basic database and a detailed database in 2011 and 2012. In this survey, measures adopted for power conservation were also investigated. We have reported the results of the survey at academic meetings in Japan [6-16]. This paper was prepared based on these papers [6-16] upon revision and editing to focus on energy consumption and measures adopted for power conservation among commercial buildings before and after the disaster.

1. Introduction

The Great East Japan Earthquake occurred on March 11 of 2011. Within several hours after the earthquake, the Fukushima nuclear crisis occurred and several thermal power plants were damaged [1]. Power supply was suspended for certain times in the Kanto and Tohoku regions for two weeks just after the disaster as an emergency countermeasure. Furthermore, in order to avoid unplanned power outages in the summer of 2011, the application of restrictions on electricity use to customers who had been supplied with electricity by Tokyo Electric Power Company and Tohoku EPCO in parts of the Kanto and Tohoku regions directly affected by the Great East Japan Earthquake was decided by the Japanese government on May 13, 2011. This step was taken for the first time since 1974. It required the large power customers (receiving 500kW or more on contracted demand) in both regions to reduce peak power by 15% compared with the previous year from July 1 to September 9, 2011. Small power customers (receiving less than 500kW on contracted demand)

Figure 1 Regions in Japan

were also strongly urged to make the same reduction [2]. Furthermore, operational nuclear power plants of each electric power company have been shut down for inspection, while others undergoing periodic inspection have not been restarted yet. The lack of power supply spread to the Kansai and Kyushu regions by the summer of 2011. Thus, while the background reasons were different, power conservation especially at peak time on weekdays was required all over Japan, and many kinds of measures were implemented to this end. A map of Japan is shown in Figure 1 as a reference.

These measures were on the level of emergency response, but knowledge of various items (e.g., the organization for planning measures, the measures taken, their effects, and ongoing measures) is highly valuable for the planning of measures for energy conservation and peak-shaving in normal times.

As for fact-finding investigation of energy consumption and measures adopted to save power in the summer of 2011, there are two major questionnaire surveys which were conducted without DECC Committee participation: one with small power customers conducted as a part of “Support for power-saving measures to limit power demand” by the METI (Ministry of Economy, Trade and Industry) [3-4], and the other on measures for electricity supply and demand in the summer of 2011 conducted by the Japan Business Federation [5]. The former survey is valuable for knowledge of the facts of power-saving measures in about 2,000 buildings of small power customers, but the volume of energy consumption data is not large (only 230 samples) enough for sufficient analysis of the effect of the measures. The latter survey concerns only the measures adopted and does not cover energy consumption, and the number of samples is about 90 enterprises.

In contrast, an investigation on energy consumption of commercial buildings across Japan titled “Urgent Survey on Actual Condition of Power Conservation in Summer” was conducted by the DECC Committee from October to December of 2011 and provided additional data for the basic database. This survey also investigated measures taken to save power. Regarding the detailed database, a similar investigation was conducted at the same time, and an additional survey was made from October to December of 2012. We have reported the survey results at academic meetings in Japan [6-16].

This paper was prepared based on these papers [6-16] upon revision and editing to focus on energy consumption and measures adopted for power conservation in commercial buildings before and after the disaster. This paper is composed as follows.

a. Analysis on energy consumption during the half a year after the disaster (April to September of 2011), and measures adopted for power conservation in commercial buildings in Japan based on the “Urgent Survey on Actual Condition of Power Conservation in Summer”, which is a part of an investigation on the DECC basic database.

b. Report of detailed energy consumption and peak demand in office buildings in the Kanto, Chubu, and Kansai regions in FY2011 and FY2012 (Japan’s fiscal year runs from April 1 to March 31 in the following year) based on the investigation on the DECC detailed database

2. Change in energy consumption before and after the disaster based on the DECC basic database

2.1 Outline of the survey “Urgent Survey on Actual Condition of Power Conservation in Summer”

The purpose of the survey “Urgent Survey on Actual Condition of Power Conservation in Summer” was to clarify the facts of power conservation in commercial buildings in the summer of 2011. Regarding the method of the survey, questionnaires were posted to 8,640 buildings which have already been registered with the basic database of the

Table 1 Question items on the questionnaire

The power-saving measure in the summer of 2010 and 2011	Method of implementing measures for power conservation and saving electricity consumption at peak time（Numerical target for saving electricity consumption, etc.）
	Organization for planning the measures
	Power-saving measures implemented and their continuity（44 items）
	Equipment and apparatuses for power conservation（16 items）
	Effective measures evaluated by respondents
Energy, water consumption	Monthly amount of electricity, city gus, LPG, petroleum-based fuel, and district heating and cooling, and clean water consumption from April 2010 to September 2011
Other	Contract demand of September 2010 and 2011
	Improvement or renewal of facilities in the past

DECC. The data for the attribute information of these buildings such as completion year, total floor area, and number of stairs have been recorded in the basic database. Therefore, question items for such information were removed from the questionnaires. The questionnaires were collected by return post or utilization of the answer format on a website. In addition, enterprises with chain-store operations such as convenience stores and family restaurants as well as boards of education were asked to provide the data directly. Table 1 shows the questionnaire items. They are as follows: Monthly consumption of each type of energy (i.e., electricity, city gas, LPG, petroleum-based fuel, and district heating and cooling) and water consumption from April 2010 to September 2011, Contract demand on September 2010 or 2011, Method of implementing measures for power conservation, Organization for planning the measures, Apparatuses installed for power conservation, and Power conservation measures adopted and their continuity, etc.

The number of questionnaires retrieved by means of posting and utilization of the website was 3,638. The response rate was 42.1%. In addition, there were 2,595 responses from the enterprises and boards of education. The total number of retrievals was therefore 6,233. Available samples for analysis were extracted from the responses by a screening test, which was the same method used to construct the DECC basic database [17]. As a result, the number of available samples was 3,969. The ratio of the number of available samples to that of the retrieval samples was 63.7%.

2.2 Reduction rates for monthly primary energy consumption and power consumption

Table 2 shows the average reduction rate for primary energy consumption in each building use category in each region. The upper row in the cell of the table is the average reduction rate, and the lower row, the number of samples. The reduction rate in this paper is the rate of the change in the amount of energy consumption for a certain period in FY2011 or FY2012 relative to the amount for the same period of FY2010. In this case, the period is the aforementioned half a year period. From Table 2, it can be seen that the energy consumption in 2011 was reduced in almost all categories of building use in all regions and that the average reduction rates in the Kanto and Tohoku regions were relatively higher than those in other regions. For example, regarding office buildings, the average reduction rate in the Kanto was the highest at 21.4%, followed by the Tohoku at 20.0%. In contrast, the figure in the Kansai was 12.7% and that in the Chubu was only 6.7%. As for buildings for public assembly, the figure in the Kanto was also the highest at 27.0%. As for department stores, the Tohoku figure was the highest at 27.0%.

Figure 2 shows the average reduction rates for monthly electricity consumption in buildings for typical building uses (Office, Public assembly, Commercial facility other than convenience store, Lodging, Health care) in the Tohoku, Kanto, and Kansai regions. In the case of office buildings, the average reduction rate in the Kanto in every month from April to September was over 19%. It was assumed that power conservation measures were implemented right after the disaster in the Kanto region. In contrast, the average reduction rate in the Kansai in May was only 2.0%, but reached 20.0% in September. As a reason, it is thought that awareness of the need to save power in the Kansai increased gradually with the approach of the summer of 2011 because of the gradual spread of the power supply shortage to the Kansai region. A similar tendency is found for the other building uses in the Kanto and the Kansai. In the Tohoku, the reduction rates for these building uses are relatively high in April and stay high after April, but the trend after April varies with the building uses.

Table 2 The average reduction rate for primary energy consumption during the half a year in 2011

	Office	Information Center	Public Assembly	Commercial Facility							Lodging	Health Care		Education					Culture Facility			Complex Facility	Other	Total
above: reduction rate of primary energy intensity [%] bottom: number of samples	Office	Information Center	Public Assembly	Department Store, Supermarket	Mercantile (Retail)	Convenience Store	Food Service	Appliance Store	Large Suburban Store	Retail Store	Lodging	Health Care	Welfare Facility	Kindergarten/Preschool	Education (K1-K9)	Education (K10-K12)	Higher Education	Laboratory	Theater	Exhibition Facility	Sports Facility	Complex Facility	Other	
Hokkaido	7.4%	-	6.9%	-	-	-	-	-	-	-	9.1%	4.0%	-	-	2.5%	9.7%	3.3%	-	12.6%	2.6%	-	-	-	-
	7	0	1	0	0	0	0	0	0	0	7	42	0	0	15	72	16	0	6	58	0	0	0	224
Tohoku	20.0%	-	17.7%	27.0%	-	16.4%	-	-	-	-	16.8%	12.9%	8.4%	-	-	18.2%	27.7%	11.9%	27.8%	26.3%	14.6%	-	-	-
	101	0	37	35	0	608	0	0	0	0	34	36	59	0	0	92	18	4	15	21	2	0	0	1,062
Hokushinetsu	14.9%	-	13.3%	13.9%	14.0%	-	-	17.6%	-	2.0%	12.1%	5.5%	7.9%	-	-	-	-	-	11.0%	32.6%	8.0%	3.3%	-	-
	15	0	90	19	1	0	0	1	0	1	9	39	32	0	0	0	0	0	9	3	7	2	0	228
Kanto	21.4%	-	27.0%	21.5%	30.8%	-	-	-	26.2%	-	16.3%	13.7%	18.2%	15.8%	24.0%	23.9%	23.5%	20.0%	28.0%	28.3%	26.5%	28.5%	21.8%	-
	136	0	131	25	6	0	0	0	14	0	53	73	103	5	202	29	18	29	41	61	12	3	3	944
Chubu	6.7%	9.8%	11.1%	4.2%	-	-	18.6%	-	-	-	7.8%	8.3%	9.8%	-	-	-	12.1%	6.1%	6.1%	5.6%	7.6%	6.1%	15.3%	-
	87	1	16	6	0	0	7	0	0	0	12	60	12	0	0	0	18	8	28	14	10	11	6	296
Kansai	12.7%	0.5%	10.9%	8.3%	8.7%	-	10.4%	-	15.7%	-	8.0%	3.5%	4.1%	9.3%	4.3%	-	-	8.8%	6.6%	6.0%	5.6%	5.9%	-	-
	135	4	63	31	13	0	2	0	3	0	42	84	23	4	8	0	0	12	29	8	35	13	0	509
Chugoku, Shikoku	8.7%	-	7.8%	5.3%	-	-	-	3.2%	10.0%	-	4.8%	3.7%	5.9%	-	-	-	-	-	8.6%	9.0%	3.5%	-	5.6%	-
	67	0	94	21	0	0	0	1	1	0	27	55	84	0	0	0	0	0	33	28	9	0	61	481
Kyushu	8.7%	-	12.0%	12.4%	5.3%	-	-	-	-	-	3.5%	0.4%	2.2%	-	4.4%	-	7.9%	7.0%	7.5%	6.5%	10.0%	-0.7%	8.2%	-
	46	0	40	9	10	0	0	0	0	0	12	28	3	0	2	0	9	2	5	24	10	3	22	225
All regions	14.3%	2.3%	15.8%	15.4%	12.2%	16.4%	16.8%	10.4%	23.5%	2.0%	11.3%	6.8%	10.5%	12.9%	21.7%	15.9%	16.0%	14.5%	14.6%	14.1%	9.5%	7.3%	7.3%	-
	594	5	472	146	30	608	9	2	18	1	196	417	316	9	227	193	79	55	166	217	85	32	92	3,969

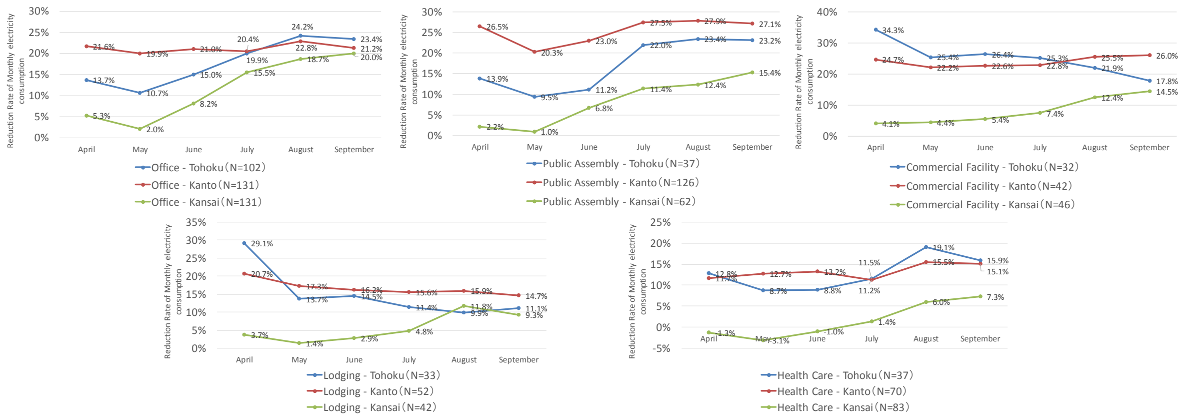


Figure 2 The average reduction rate for monthly power consumption in buildings for typical building uses in the Tohoku, Kanto, and Kansai regions

2.3 Power conservation measures implemented in 2010 and 2011

Figure 3 shows the implementation rates for power-saving measures for the small electricity customers in buildings for office, public assembly, and commercial facility other than convenience store in the Kanto and Kansai regions before and after the disaster. Figure 4 shows a similar graph for the large electricity customers. The implementation rate in this case means the number of samples implementing the power-saving measure as percentage of the total number of the samples. These figures show ten kinds of power-saving measures having significantly different implementation rates between before and after the disaster. Figures in brackets indicate the number of samples. The white bar indicates the ratio of buildings where a certain power-saving measure was implemented in 2010 and 2011. The light gray bar is the ratio of buildings where the power-saving measure was implemented in only 2011, and the deep gray bar, in only 2010. The black bar is the ratio of buildings in which the power-saving measure was not implemented in either year. Therefore, the total of the white bar plus the deep gray bar is the ratio of buildings where a certain power-saving measure was implemented in 2010, and the total of the white bar plus the light gray bar, in 2011.

According to Figure 3, before the disaster (2010), the implementation rates for almost all kinds of power-saving measures for each building in the Kansai were higher than in the Kanto. For example, the measure “Determine the amount and generation time of peak power demand” was implemented in 47% of the office buildings and 30% of the buildings for public assembly in the Kansai, but in only 29% of the office buildings and 17% of the buildings for public assembly in the Kanto. But after the disaster (2011), the implementation rate for the same measure for office buildings in the Kanto reached 78%, which is much higher than 50% in the Kansai. As for the other power-saving measures, a similar trend is also seen. This suggests that consciousness of power conservation in the Kansai was higher before the disaster and rose after the disaster, while in the Kanto it was slightly low before the disaster but increased sharply after the disaster. The measures whose implementation rate for the three kinds of buildings in the both regions was over 90% after the disaster are as follows; “Thinning out luminaires”, “Review of the AC thermostat setting in rooms”. However, for the measure “Stop operating some elevators”, the implementation rates for office buildings in the Kanto and the Kansai after the disaster differ, at 60% and 39%, respectively.

According to Figure 4, the implementation rates for power-saving measures requiring specialists or facilities engineers, such as “Adjustment of cooling period”, “Controlling peak demand at the cooling starting time”, and “Getting information on energy consumption at other buildings as a reference”, were higher than among the small electricity customers for the three kinds of buildings in both regions in both years. Regarding the other power-saving measures, before the disaster (2011), the implementation rates in the Kansai were slightly higher than those in the Kanto, in addition to the trend among the small electricity customers. For example, for office buildings, the implementation rate for “Stop operating air conditioning in unused rooms” was 81% in the Kansai but 66% in the Kanto, and the implementation rate for “Turning lights off in the daytime within the limits for working” was 53% in the Kansai but 31% in the Kanto. After the disaster (2011), the implementation rates in each type of building use in both regions increased to the same degree.

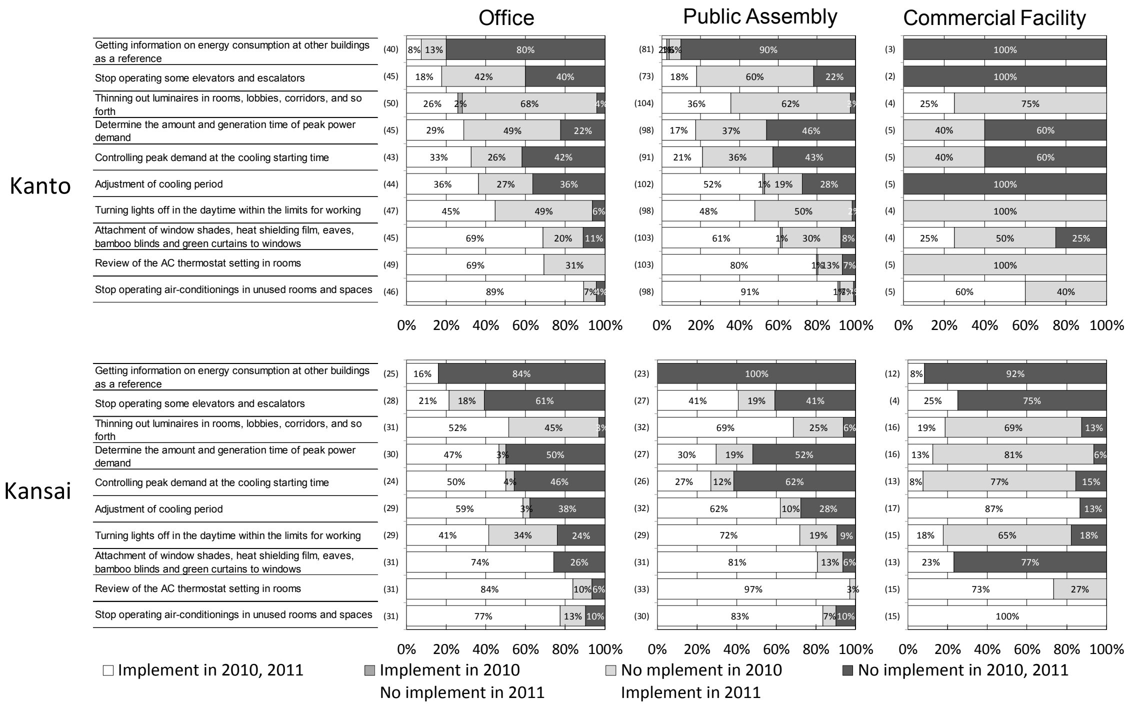


Figure 3 The implementation rates for power-saving measures in small electricity customers

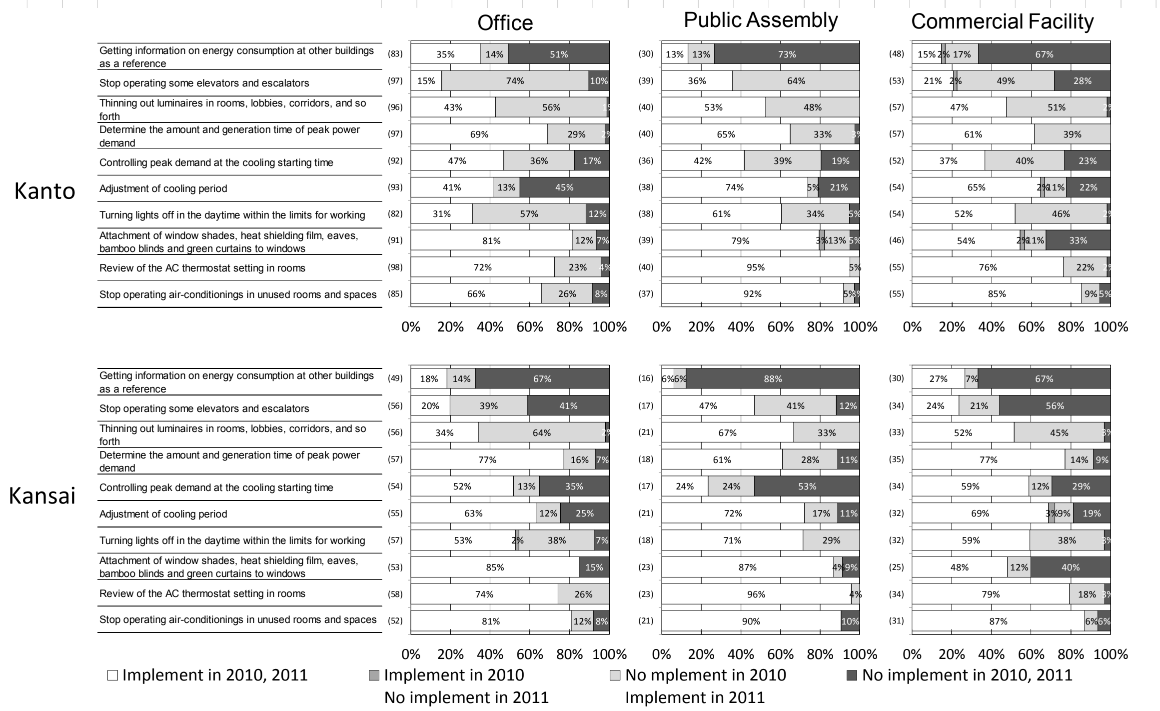


Figure 4 The implementation rates for power-saving measures in the large electricity customers

3. Energy consumption for each end use of office buildings in FY2011 and FY2012 based on the DECC detailed database

3.1 Outline of the investigation for the detailed database of the DECC in 2011 and 2012

The investigation for the detailed database was conducted in the same period as the investigation for the basic database after the disaster, and an additional investigation was conducted in 2012. The investigation subjects were 328 enterprises in 2011 and 443 enterprises in 2012. These enterprises had been subsidized for installing BEMS in buildings by the NEDO (New Energy and Industrial Technology Development Organization of Japan). These investigations collected time series data for hourly energy consumption for each end use, information on building and HVAC systems, and power-saving measures taken in each building. The period for collected energy consumption data was the 2.5 years from April 2010 to September 2012. There was some kind of reply from 178 enterprises in the investigation of 2012, and time series data for hourly energy consumption for 121 buildings were collected. Buildings in the Kanto occupy 47% of the valid responses, and office buildings occupy 41%. The details of these investigations and method of compilation of the data collected were reported in another paper [17].

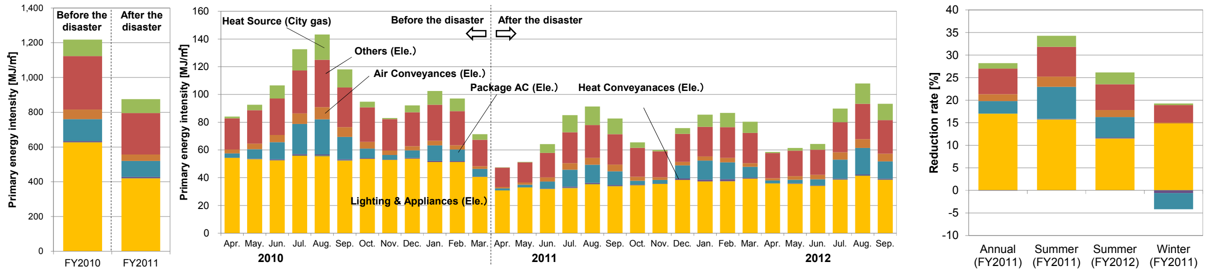
3.2 An example of energy consumption at office buildings based on the detailed database

The collected data were edited into time-series data for primary energy intensity [MJ/m^2] of floor area of each uniform end use such as Lighting & Appliances, Heat Source Equipment, Package AC, Elevator, and so on [17]. In this section, the edited data for an office building are introduced as an example.

According to the answers to the questionnaire in this example, the building is located in Tokyo and is an office with 45% of its floor area used for office work and 55% for common space such as conference rooms, lounges, and staff canteen. The total floor area is about 18,400 square meters. The building is installed with air-cooling package air conditioners and an absorption chiller-heater. Accordingly, electricity and city gas are used in this building. The numerical target for peak demand reduction in 2011 was set as more than 15% relative to the peak demand in 2010. For example, the following power-saving measures were implemented in the summer of 2011; “Determine the significant influence apparatus in power demand”, “Thinning out luminaires”, and “Turning off lights in rooms during absence”. Many kinds of power-saving measures for power equipment and electrical appliances were implemented, too. After the summer of 2011, the same measures continued to be taken but a target value for peak shaving was not set.

Annual (FY2010 and FY2011) and monthly primary energy intensity for each uniform end use in the building from April 2010 to September 2012 are shown in Figure 5. Reduction rates for primary energy intensity in the annual period (April to March) of FY2011, summer period (July to September) of FY2011, summer period of FY2012, and winter period (December to February of the following year) of FY2011 are also shown in Figure 5. The share occupied by each end use in the reduction rate is also shown.

The annual energy intensity in FY2010 was 1,218MJ/m^2, which is smaller than the average value for offices at 1,702MJ/m^2 (473kWh/m^2) in FY2008 [17]. This is presumably partly because the ratio of office space to total floor area in this building is small compared with that in ordinary office buildings, which is around 70%. The annual energy intensity in FY2011 was 876MJ/m^2. The annual reduction rate for primary energy intensity in FY2011 was 28.3%. The effect of the lighting & appliances end use on the reduction rate was the highest at 17.1%, but that of package AC and heat source (gas) was less than 4%. Regarding the reduction rate in each season, the reduction rate in the summer of FY2011 was the highest at 34%, but the reduction rate in the winter of FY2011 was 15%, which is less than half as high as the reduction rate in the summer. In the winter of FY2011, the effect of lighting & appliances maintained the same level as in the summer, but the effect of package AC was about minus 4%, which indicates an increase in energy consumption for this end use. This is because internal heat in winter was reduced by the influence of reduction of energy consumption for lighting & appliances, and then the heat load increased. As for the reduction rate of an end use itself, the rate for lighting & appliances tended to decline with time; it was 38.0% in the summer of FY2011, 28.2% in the winter of FY2011, and 27.6% in the summer of FY2012. The reduction rates for the package AC itself were 44.0%, -42.2%, and 28.2% respectively.

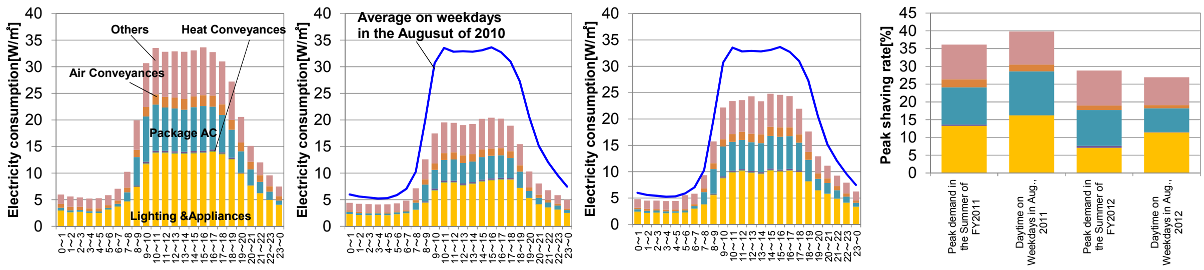


Annual **Monthly** **Reduction rate**

Figure 5 Annual and monthly primary energy intensity for each end use, and reduction rates

Figure 6 shows hourly average electricity intensity on weekdays in August in each year and peak shaving rates in each period. Figure 7 shows hourly average energy consumption on weekdays in January in each year and peak saving rates in each period. The peak shaving rate is an evaluation of the electricity consumption reduction in peak time or daytime compared with 2010. The peak shaving rate of peak demand in the summer is the ratio of the difference of peak demand between the summer of FY2011 or FY2012 and FY2010 to the value for FY2010. The peak shaving rate in the daytime in August is the rate of the change in the amount of the hourly average electricity consumption from 1:00 P.M. to 4:00 P.M. on weekdays in August 2011 or 2012 relative to the amount in August 2010. The same definition is applied for the peak shaving rate in the winter (January), mutatis mutandis.

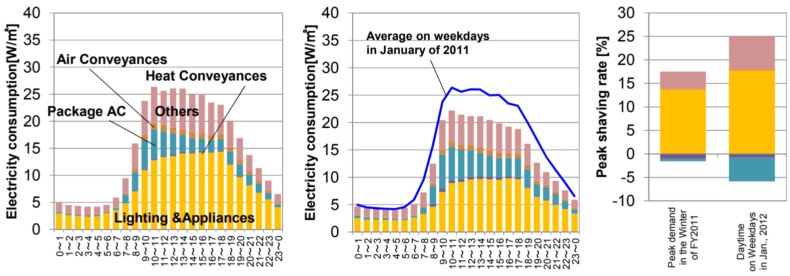
According to Figure 6, the peak shaving rate for peak demand in the summer of FY2011 was 36.2%. The effect of the lighting & appliances end use was the highest at 13.2%, and that of package AC, 10.5%. The peak shaving rate in the daytime in August 2011 was 39.9%. However, the peak shaving rate for peak demand in the summer of FY2012 was 28.8%, and the value in the daytime in August 2012 was 27.0%. The peak shaving rate in the daytime in August 2012 decreased by more than 10 points compared with 2011. As for the peak shaving rate for each end use itself, the rate in the daytime for lighting & appliances itself was 39.2% in August 2011 and 27.6% in August 2012. The rate for package AC itself was 49.8% in August 2011 and 26.9% in August 2012. It can be seen that the peak shaving rates for lighting & appliances and package AC have a high correlation in summer.



August,2010 (Before the disaster) **August,2011** (After the disaster) **August,2012** (After the disaster) **Peak Shaving Rate**

Figure 6 Hourly average electricity intensity on weekdays on August in each year and peak saving rates

According to Figure 7, the peak shaving rate for peak demand in the winter of FY2011 was 15.9%, and that in the daytime in January 2012 was 19.2%. The effect of the lighting & appliances end use was 17.7%, but that of the package AC end use, -5.0%. It is thought that indoor heat load increased in winter under the influence of internal heat decrease. As for the peak shaving rate in the daytime in January 2012 for each end use itself, the rate for lighting & appliances itself was a little less than 30%. This suggests that awareness of the need to save power went into gradual decline after the summer of 2011.



January, 2011 (Before the disaster) **January, 2012** (After the disaster) **Peak Shaving Rate**

Figure 7 Hourly average electricity intensity on weekdays in January in each year and peak saving rates

Figure 8 shows the relation between daily average outside air temperature and daily primary energy consumption on weekdays in the summer and the winter. The data are plotted on the graph where the vertical axis is daily primary energy consumption and the horizontal axis is daily average outside air temperature. The data for outside air temperature are measurements taken at a measurement point of the Japan Meteorological Agency located near this building [18]. A regression line is generated using the relationship between these data in each season. According to Figure 8, the data have a high correlation. The coefficient of determination in the equation was 0.79 in the summer of FY2010, 0.50 in the summer of FY2011, 0.54 in the summer of FY2012, 0.43 in the winter of FY2010, and 0.52 in the winter of FY2011. In the summer, the difference between the trend for FY2011 or FY2012 and that for FY2010 is clearly apparent. The inclination of the trend for FY2012 is sharper than that for FY2011. This suggests that consciousness of power conservation in FY2012 was lower than in FY2011. In addition, the distribution of the daily average outside air temperature in FY2012 was concentrated in a higher position compared with FY2011. It is thought that these factors affected energy consumption in the summer of FY2012 and then the value increased a little compared with FY2011. In the winter, the difference between the trends for FY2010 and FY2011 is also clear, but as the outside air temperature lowers, the difference is reduced. In this building, the main heating system is an air heat source package air conditioner. The energy efficiency of the air heat source package AC in heating declines as the air temperature decreases. In addition, the ratio of energy consumption for the package AC to the energy consumption of the building in winter of FY2011 was higher than in 2010 because the heating load increased along with the internal heat decrease, under the influence of the power-saving measures implemented for lighting & appliances. Therefore, it is thought that the previously described phenomenon occurred due to the synergistic effect of these factors.

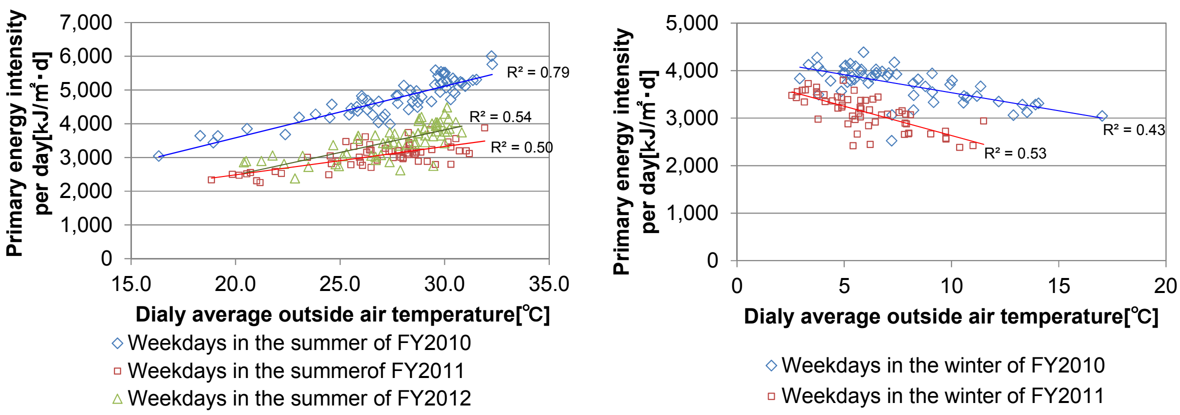


Figure 8 The relation between daily average outside air temperature and the daily primary energy intensity on weekdays in the summer and the winter

Figure 9 shows the relation between daily average outside air temperature and the daily peak demand on weekdays in the summer and the winter. The trend is similar to that of primary energy consumption.

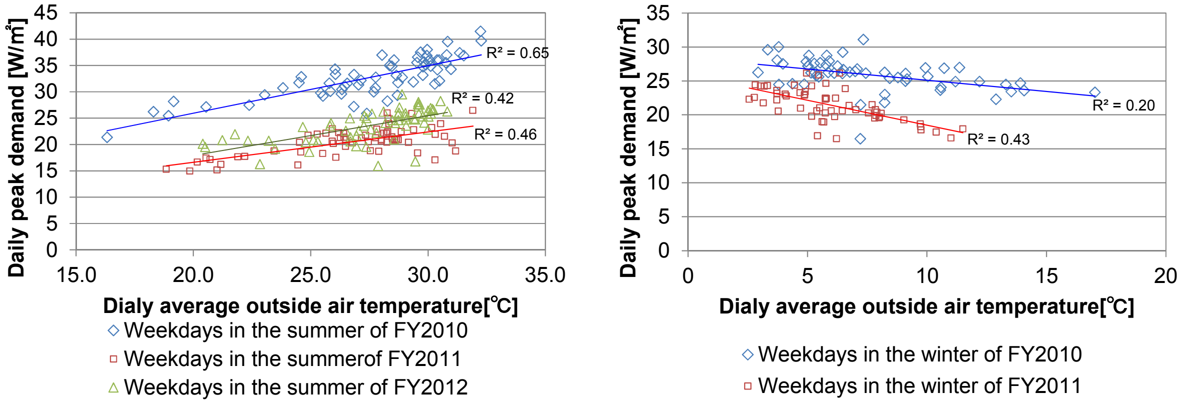


Figure 9 The relation between daily average outside air temperature and the daily peak demand on weekdays in the summer and the winter

3.3 Analysis on change in energy consumption and peak demand in office buildings

Change in energy consumption and peak demand in office buildings in the three regions of the Kanto, Chubu, and Kansai before and after the disaster is analyzed by the same method. Table 3 outlines the buildings in the analysis. These buildings were located in the Kanto, Chubu, and Kansai regions, and numbered 19, three, and nine, respectively.

Table 3 Outline of buildings in the analysis

No.	Ownership	Location	Floor Area	Completion Year	Number of stairs		Ratio of Office	Main cooling heat source equipment		DHC	Thermal strage tank	Package AC
			m²		Aboveground floor	Underground floor	%	Electricity	City gas			
1	Owner	Kanto	10,800	1991	5	1	100	○			○	○
2	Nonowner	Kanto	9,400	1988	6	0	100					○
3	Nonowner	Kanto	25,500	1991	16	1	100			○		○
4	Owner	Kanto	18,400	1990	11	4	45					○
5	Nonowner	Kanto	5,100	1988	9	1	100	○			○	
6	Owner	Kanto	18,800	1976	5	2	55	○			○	
7	Nonowner	Kanto	11,800	1985	8	3	70	○	○		○	
8	Owner	Kanto	10,400	1993	5	1	50					○
9	Nonowner	Kanto	21,800	1994	4	1	96	○	○		○	○
10	Nonowner	Kanto	49,200	1982	15	3	100	○	○			
11	Owner	Kanto	29,700	1969	18	3	100	○	○			○
12	Nonowner	Kanto	15,200	1989	8	1	85	○			○	○
13	Nonowner	Kanto	7,100	1990	7	2	80					○
14	Owner	Kanto	164,300	1993	26	1	100			○		○
15	Owner	Kanto	12,600	1992	10	0	91					○
16	Owner	Kanto	183,100	1976	54	4	70			○		
17	Nonowner	Kanto	130,200	1968	36	3	67		○			○
18	Nonowner	Kanto	9,700	1989	8	1	71					○
19	Owner	Kanto	39,100	1992	22	1	99			○		
20	Owner	Chubu	43,200	1963	12	3	81	○			○	○
21	Owner	Chubu	6,200	1991	8	1	100	○	○			
22	Nonowner	Chubu	34,600	1987	18	2	98	○	○			
23	Owner	Kansai	22,200	1983	13	2	*35	○	○			
24	Owner	Kansai	23,400	2003	18	1	61	○	○		○	○
25	Owner	Kansai	51,300	2001	18	2	100	○	○		○	○
26	Owner	Kansai	13,000	2003	11	2	90	○			○	○
27	Nonowner	Kansai	23,300	1984	8	1	65	○	○			○
28	Nonowner	Kansai	90,300	1962	15	4	59	○	○		○	○
29	Nonowner	Kansai	15,700	1992	8	1	58	○	○			
30	N/A	Kansai	11,300	1989	5	0	*24	○				○
31	Owner	Kansai	19,200	1993	14	2	57	○				○

*The value is low but the main building use is regarded as an office according to the building information on the website

3.3 The change in energy consumption before and after the disaster

Annual primary energy intensity in each region in FY2010 and FY2011 and the related reduction rates are shown in Figure 10. Figures in brackets indicate the number of samples. In Figure 10, the respective average annual primary energy intensity in FY2010 and FY2011 was 2,138MJ/m² and 1,743MJ/m², in the Kanto, 2,291MJ/m² and 2,147MJ/m² in the Chubu, and 1,903MJ/m² and 1,777 MJ/m² in the Kansai. The average reduction rate in FY2011 was 21.2% in the Kanto, 7.3% in the Chubu, and 6.6% in the Kansai. The reduction rate for the Kanto is over 10 points higher than those in the other regions.

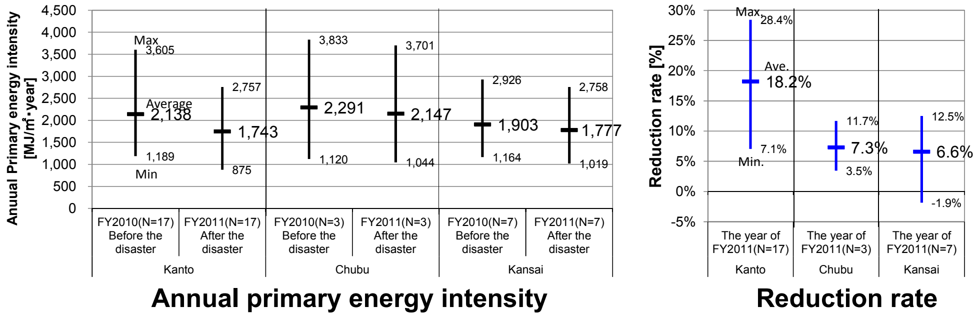


Figure 10 Annual primary energy intensity and the reduction rate

Monthly average primary energy intensity in the summer (July to September) of FY2010, FY2011, and FY2012 and the reduction rates are shown in Figure 11. In addition, to eliminate influence of outside air temperature from energy consumption, a predicted reduction rate at 27°C was calculated using a regression line generated with the relationship between daily average outside air temperature and daily primary energy consumption of each building as noted in Section 3.2. The predicted reduction rate of 27°C is the ratio of the difference of the daily energy consumption in each period between FY2011 or FY2012 and FY2010, which is calculated with the equation of the regression line when the temperature setting is 27°C, to the calculated value in the same period of FY2010. Samples which have a value of 0.1 or more as the coefficient of determination of the regression line are used for the calculation in this study. The 0.1 coefficient of determination is low, but it is thought that error is relatively small because 27°C as the temperature setting is near the seasonal average outside air temperature in these regions. For example, the average outside air temperatures in Tokyo in the summer of FY2010, FY2011, and FY2012 were 27.6°C, 26.7°C, and 27.5°C, respectively [18]. In this connection, the average coefficient of determination of the regression line in the summer of FY2010 is relatively high at 0.76, and the values for FY2011 and FY2012 are 0.58, 0.34, respectively. The predicted reduction rate at 27°C is also shown in Figure 11 as a reference.

According to Figure 11, the average reduction rates in the summer of FY2011 and FY2012 were 24.6% and 21.9%, respectively, in the Kanto, 13.5% and 14.1% in the Chubu, and 11.3% and 7.7% in the Kansai. However, the reduction rates predicted at 27°C in FY2011 and FY2012 were 23.9% and 24.2%, respectively, in the Kanto, 15.6% and 21.3% in the Chubu, and 11.5% and 10.0% in the Kansai. The reduction rate in the Kanto in FY2012 was about 3 points lower compared with FY2011, but the predicted reduction rate for FY2012 was almost the same level as for FY2011. The trend in the Kansai is similar to that in the Kanto. In contrast, the predicted reduction rate for the Chubu was 5.7 points higher. This suggests that in the Kanto and Kansai, the extent of measures implemented for power saving in the summer of FY2012 was not different from that in the summer of FY2011, but in the Chubu, that in the summer of FY2012 was higher.

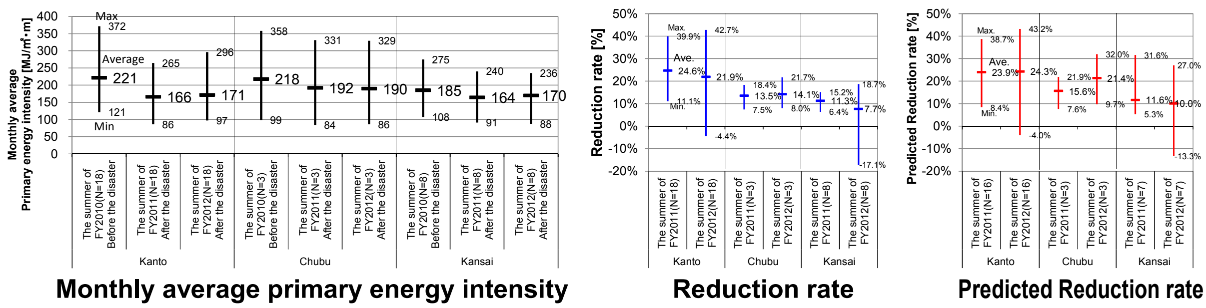


Figure 11 Monthly average primary energy intensity and the reduction rate in summer

Monthly average primary energy intensity in the winter (December to February) of FY2010 and FY2011, and the reduction rate and the predicted reduction rate at 7°C are shown in Figure12. The predicted reduction rate is calculated using the regression line generated with the relationship between the data on weekdays in the winter when the temperature setting is 7°C, which is near the seasonal average outside air temperature in these regions, for example, 7.7°C in the winter of FY2010 and 6.0°C in that of FY2011 in Tokyo [18].

The reduction rates for the Kanto, Chubu, and Kansai came to 10.6%, -0.2%, and 2.8%, respectively. The predicted reduction rates at 7°C were 13.8%, -4.8%, 7.3%, respectively. The predicted reduction rates in the Kanto and Chubu decreased by over ten points compared with the rates for the summer, but the rate in the Kansai was basically on a par with the rate for the summer.

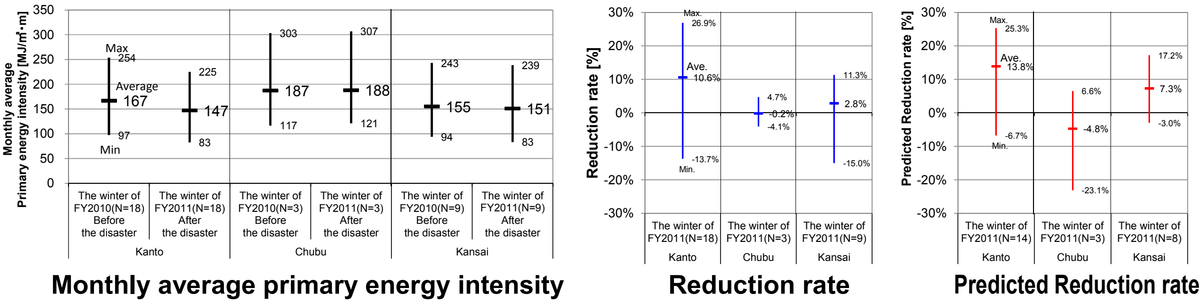


Figure 12 Monthly average primary energy intensity and the reduction rate in winter

The reduction rates for primary energy consumption for lighting & appliances and AC equipment themselves in each period are shown in Figure 13. The AC equipment consists of heat source equipment, auxiliaries, heat conveyances, air conveyances, and package AC. In the figure, the average reduction rates for energy consumption for lighting & appliances for the year in FY2011, the summer of FY2011, FY2012 and the winter of FY2011 in the Kanto were 20.9%, 26.7%, 24.0%, and 16.1%, respectively. The reduction rate in the summer of FY2011 was the highest. The trend in the other regions is similar to that in the Kanto, but the rate for the year in FY2011 was lower than in the Kanto, at 7.7% in the Chubu and 6.2% in the Kansai. As for the AC equipment, the reduction rate in the Kanto was 25.7% in the summer of FY2011, but decreased to 0.7% in the winter of FY2012. The general trends in the other regions are similar to that Kanto.

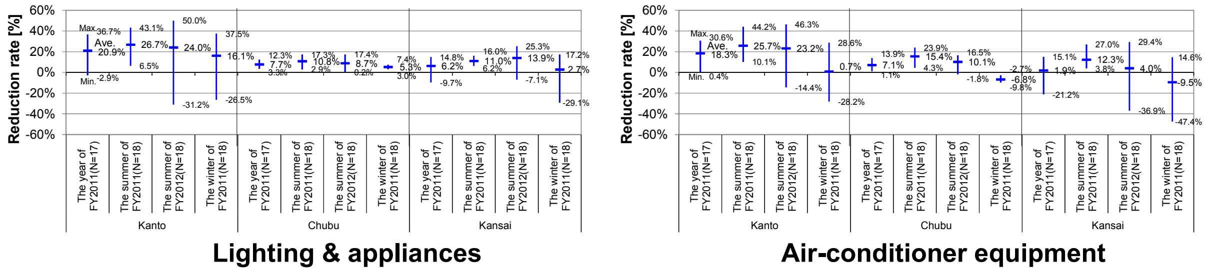
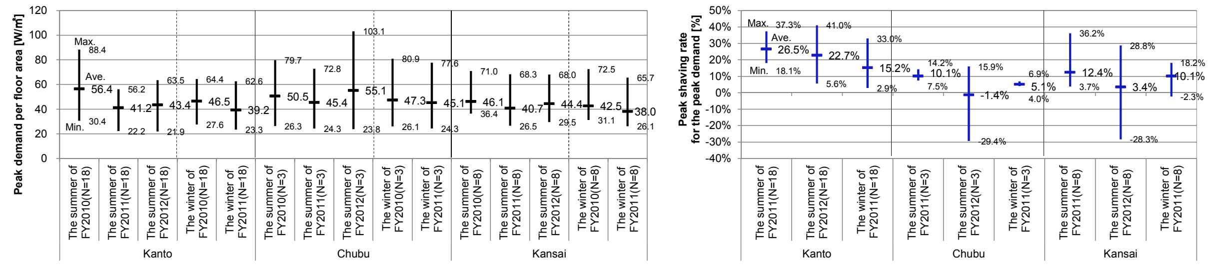


Figure 13 The reduction rates for primary energy consumption for lighting & appliances and AC equipment in each period

3.4 The change in peak demand before and after the disaster

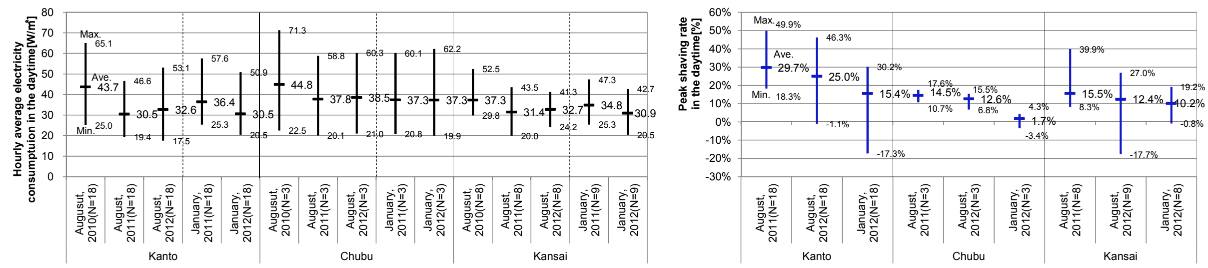
The peak demand per floor area of office buildings in each region in the summer and the winter of each fiscal year and the peak shaving rate of peak demand are shown in Figure 14. The hourly average electricity intensity in daytime (13:00-16:00) on weekdays in August of 2010, 2011, 2012, January of 2011, 2012 and the peak shaving rate in daytime are shown in Figure 15.

As shown in Figure 14, the average peak shaving rate for the peak demand in the Kanto in the summer of FY2011 and FY2012 was relatively high at 26.5% and 22.7%, respectively. The average peak shaving rate in the Chubu and the Kansai in the summer of FY2011 was around 10%, but fell to a few percent in the summer of FY2012. In the winter, it decreased to 15.2% in the Kanto, 5.1% in the Chubu, and 10.1% in the Kansai. In Figure 15, the peak shaving rate in the daytime in the Kanto exhibits the same trend as the peak shaving rate for the peak demand at 29.7% in August 2011, 25.0% in August 2012, and 15.4% in January 2012.



Peak demand per floor area **Peak shaving rate for the peak demand**

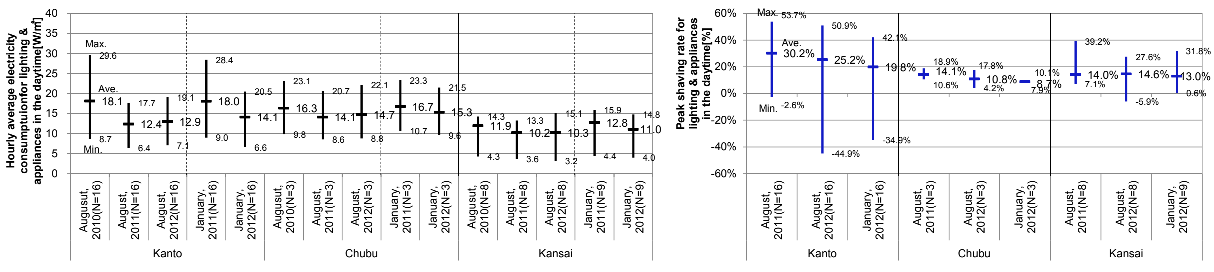
Figure 14 Peak demand per floor area of office buildings in each region in the summer and the winter and peak shaving rate for the peak demand



Hourly average electricity consumption in daytime **Peak shaving rate in daytime**

Figure 15 Hourly average electricity intensity in the daytime on weekdays of August and January and peak shaving rate in the daytime

Figure 16 shows hourly average electricity consumption for lighting & appliances per floor area in the daytime on weekdays in August 2010, 2011, 2012 and January 2011, 2012 and peak shaving rate for lighting & appliances itself in the daytime. The peak shaving rate in August 2011 in the Kanto was 30.2%, decreased to 19.8% in January 2012, and increased to 25.2% in August 2012. This trend corresponds with that of primary energy consumption (Figure 13). As for the reason, it can be pointed out that the extent of power-saving measures implemented for lighting & appliances was reduced temporarily in the winter. The peak shaving rate in Kansai was 10 to 15% in each period.



Hourly average electricity consumption in daytime **Peak shaving rate in daytime**

Figure 16 Hourly average power consumption for lighting & appliances per floor area in the daytime on weekdays in August 2010, 2011, 2012 and January of 2011, 2012 and peak shaving rate for lighting & appliances itself in the daytime

4. Conclusion

This study reported the result of two investigations conducted by the DECC Committee as to the effect on energy consumption in commercial buildings in Japan exerted by the influence of the Great East Japan Earthquake, which occurred on March 11, 2011. The results of the investigation of the DECC basic database may be summarized as follows.

- From the average reduction rate for primary energy consumption during the half a year period in FY2011, it can be seen that the energy consumption in 2011 was reduced in almost all categories in all regions. The average reduction rates in the Kanto and Tohoku regions were higher than those in other regions.
- The trend of the reduction rate for monthly electricity consumption in buildings in the Tohoku, Kanto, and Kansai regions from April to September of 2011 shows that the rate in the Kanto in every month was high. In contrast, the rate in the Kansai was low in April but increased gradually with time until September. This is presumably because power-saving awareness in the Kanto rose to a very high level just after the disaster due to the experience of the planned power outage in the Kanto and Tohoku regions for two weeks immediately after the disaster. In contrast, awareness in the Kansai increased gradually toward the summer of 2011 as the problem of power supply shortage gradually spread there.
- Regarding the power-saving measures implemented, “Thinning out luminaires”, “Review of the AC thermostat setting in rooms” and “Stop operating air-conditionings in unused rooms and spaces” were implemented in over 90% of the buildings in the Kanto and the Kansai in 2011.

The results of analysis on the several detailed data concerned with office buildings may be summarized as follows.

- The average reduction rates in the summer of FY2011 and FY2012 were 24.6% and 21.9%, respectively, in the Kanto, 13.5% and 14.1% in the Chubu, and 11.3% and 7.7% in the Kansai. However, the predicted reduction rate in the Kanto and the Kansai in FY2012, which was calculated to eliminate the influence of outside air temperature, was almost the same level as in FY2011. The trend for the peak shaving rate in the summer was similar.
- The average reduction rate in the winter of FY2011 was 10.6% in the Kanto, -0.2% in the Chubu, and 2.8% in the Kansai. These rates were lower than that in the summer.
- As for end use of lighting & appliances, the reduction rate itself and peak shaving itself remained relatively high in the summer of 2011 and 2012, but decreased in the winter. It can be pointed out that the extent of power-saving measures implemented for lighting & appliances was reduced temporarily in the winter because of the influence of the idea that, energy consumption of office buildings in a city like Tokyo in winter is smaller than in summer.
- The rate for AC equipment in summer was high and had a high correlation with that for lighting & appliances, but that in winter was low. The rate was minus for some buildings, especially those in which air-source package air conditioners were installed as the main heating system. This is presumably due to an increase in the indoor heat load in winter under the influence of internal heat decrease. The implication is that it is more difficult to save power in winter than in summer.

The environment surrounding energy consumption in commercial buildings in Japan after the disaster constantly changed owing to factors such as the change in public awareness, transition from emergency measures to standing measures, need to save power due to the shutdown of nuclear power plants, power tariff hikes, and change in government policy. Therefore, it is unknown whether or not the DECC database constructed before the disaster is still valid. However, the change of energy consumption due to the environmental changes could provide valuable information for the future planning of power-saving measures. Accordingly, it is very important to investigate it on a continuous basis.

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Session

Examples

Introducing (energy) design processes into Austria's largest public real estate company

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Abstract

Owning real estate assets comprising roughly 2.500 buildings, the Bundesimmobiliengesellschaft m. b. H. (BIG) is one of Austria's most important property owners. Its core business is management and administration of properties, ranging from new construction to demolishing. Given this number of buildings, a high annual number of building refurbishments is necessary in order to meet the needs of the buildings' tenants.

However, the BIG's resources for these restorations are limited. For each project, the demand of financial resources must not exceed the planned limit. Costs for additional investments (e.g. for energy efficient measures), which lead to lower energy demand during operation, would have to be taken over by the tenants. Yet, the tenants – mainly Ministries, Universities et cetera – struggle to cope with limited budgets themselves. There is hardly any budget at hand for investments in the building itself. In the case of refurbishments, the BIG is trapped in a classic investor-user-dilemma, which generally leads to conventional instead of sustainable and innovative restorations.

The project BIGMODERN tackles these barriers in a thorough and structured manner, aiming for the following objectives in particular:

- Establishment of two large demonstration projects in order to show and evaluate the practicability of sustainability- and energy efficiency-criteria in specific modernization-schemes. Hence the long time profitability (by calculating life cycle costs) and functionality of the measures will be dwelt on.
- Inquiry of energy demand data and other usage data, by the help of which the success of the taken measures can be analyzed and evaluated.
- Embedding adapted (as appropriate) sustainability- and energy efficiency-criteria in essential guiding principles of planning- and execution-processes, based on know-how and experience gathered in planning and executing the construction work of the demonstration projects.

1 Introduction

The Bundesimmobiliengesellschaft (BIG) is a service provider for the Republic of Austria, its subordinated departments and its outsourced companies. BIG's core business is the management and administration of real property from new construction to deconstruction. Since 2000 about 2,800 properties that were acquired by the Republic of Austria are owned by BIG (cf. Figure 1). Approx. 1,200 of these properties were built in the period between the 1950s and the 1980s.

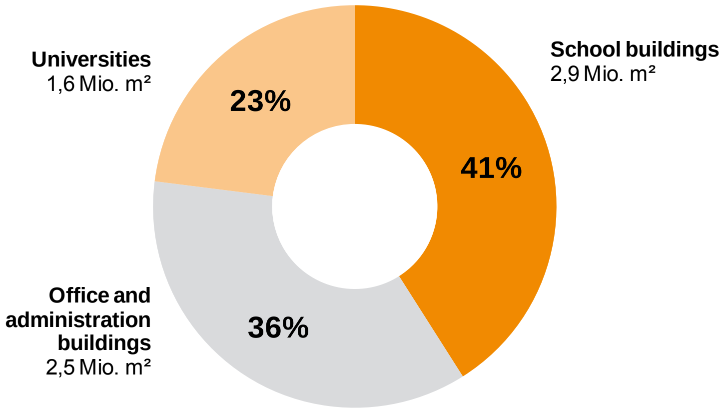

Figure 1: Overall useful area of BIG-buildings, sorted by use (source: BIG)

BIG is the landlord and owner of the properties. General refurbishments of BIG are commissioned by the tenants of the very buildings. The standard process of BIG is presented in Figure 2: First of all, the budget for construction is approved by the Finance Ministry and distributed to the federal ministries. Within these ministries, the projects and the requirements are evaluated in cooperation with the users of the building. Having selected the projects, the design phase starts. Only after the lease contract is signed at the draft stage of the design, the BIG is entrusted with the implementation of the project.

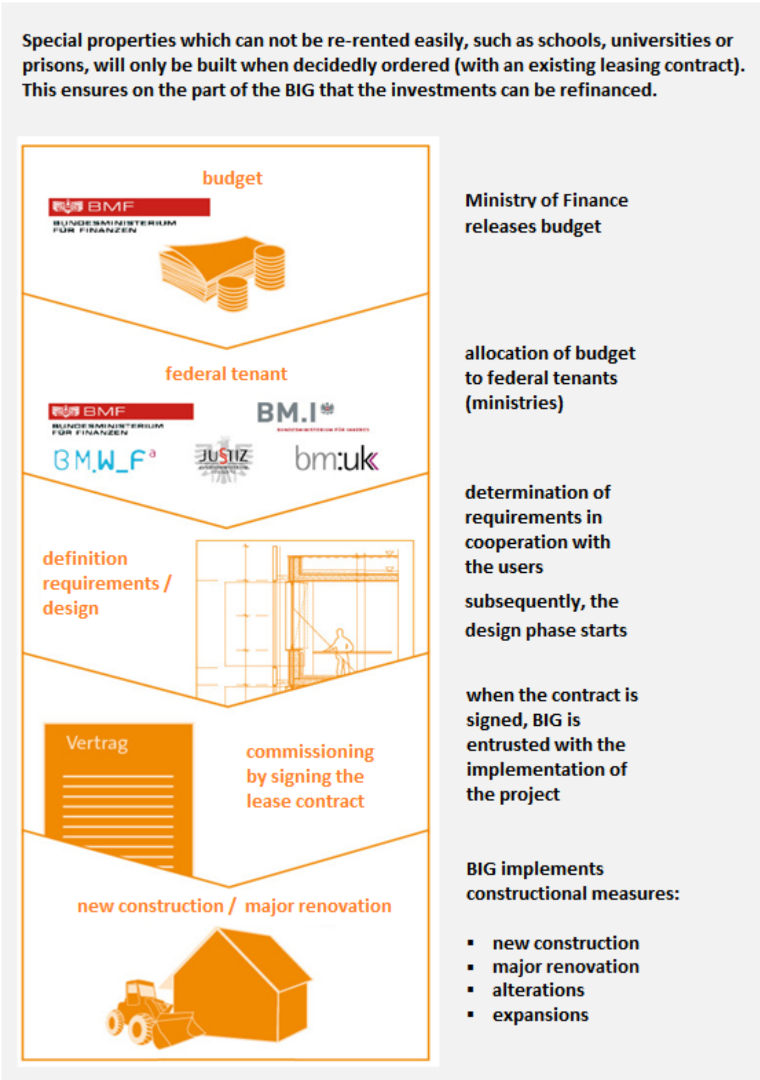

Figure 2: standard procedure as applied by BIG for complete refurbishments (source: BIG)

The framework conditions BIG has to comply with aggravate complete refurbishment efforts. On the one hand, BIG has the public contract to implement a sustainable, highly energy-efficient refurbishment, but on the other hand BIG also has to take economic aspects into account. Not least, the revisions of the EU Buildings Directive (2010/31/EU) and the Energy Service Directive (2006/32/EC) emphasize the role model function of the public sector. Yet, BIG only has quite limited resources at its disposal for each of its reconstruction projects which mustn't be exceeded. Any additional costs for investments that reduce energy demand in operation would have to be borne by the tenants. The tenants, however – most often ministries, universities, etc. – are also struggling with limited budget resources, as means for investments in buildings are seldom envisaged in the budget. This entails that the BIG gets caught in the classic investor-user dilemma during renovations, which usually leads to conventional and not sustainable or innovative remediation.

2 Objective

While BIG has already implemented several energy-efficient and climate-friendly flagship projects as far as new buildings are concerned (e.g. Haus der Forschung in Vienna, passive house Jungstraße in Vienna), functional refurbishments and major renovations are still carried out according to the state of the art in a conventional way and are just adjusted to the local regulations and building codes.
In view of the public contract to build sustainably and given the high proportion of modernization projects at the total investments of the BIG, consistent steps from conventional towards innovative solutions are demanded increasingly, especially in this sector.

In practice, a number of barriers arise which aggravate the implementation beyond individual cases:

- usually, the tenants of BIG-buildings are government departments and universities, which are calling for comfort and functionality. In order to achieve high standards both for the comfort of use as well as sustainability and energy efficiency in renovation, measures with new technologies are necessary, which have not yet been tested in many projects. This situation involves considerable risks both for the client and for the planners, which is why the BIG often eschews innovative solutions and relies on proven, but not very innovative measures;
- sustainable and energy efficient refurbishments require new design processes, in which the sub plans interweaved more closely in order to enable the planners to realize adjustment and optimization processes between individual trades (integrated design);
- in the sector of building management, investment decisions regarding modernizations are also largely based on production costs. However, in order to be able to implement innovative, climate-friendly modernizations, the operating costs throughout the life cycle have to be integrated to a greater extent in addition to the construction costs for providing an appropriate basis for investment decisions. As far as this point is concerned, the BIG is caught in a classic investor-user dilemma. Higher investment costs due to innovative activities often cannot be financed on the part of the tenants because of the strict limits on budget funds imposed by the ministries in charge.

3 Methods

To overcome these barriers, the research project BIGMODERN has been launched in 2009. The core element of the flagship project is the implementation of two demonstration projects. Both projects are modernization projects of federal buildings of the construction period between the 1950s and the 1980s. For both buildings the architectural competition had already been completed and even at this stage emphasis was placed on energy efficiency. Within the scope of accompanying research, decisions necessary for the implementation of these demonstration projects are supported scientifically by several sub-projects.

The following aspects are provided in detail:

- Implementation of a life-cycle cost analysis (LCCA) accompanying the design phase in order to filter out those of different variants, which are optimal in cost over the whole life cycle and not just in initial investment.
- Moderation of an integrated design process to make all relevant trades work together for the sake of achieving the development of an optimum for the building.
- Feasibility studies for the use of innovative, but for sustainable modernization indispensable technologies to reduce the (perceived) risk on the part of the planner and the client;
- In addition, a monitoring system to evaluate the demonstration projects will be established as the basis for the subsequent dissemination of project results.

In the evaluation and documentation part, knowledge and experience gained from design and implementing the demonstration projects will be evaluated collectively. Eventually, specifications of standard goal criteria for sustainable and energy efficient modernization as well as for matching standard planning processes are developed. These standard guidelines will subsequently apply for all modernization projects of BIG in existing buildings of the construction period between the 1950s and the 1980s.

In addition, a concept is developed, how to include both natural resource-saving and operating cost reducing modernization measures into the contractual relationships between the BIG and the respective user departments as well as the planners and builders. In this concept the total costs of use (net cold rent plus operating costs) serve as a basis.

4 The process of integrated planning

In the following chapters the process of integrated planning, which has been used in two demonstration projects, is described.

4.1 Overview

The integrated design process has been an issue in the construction industry for several decades. A key motivation for this is the increase in requirements for buildings that need to be covered during the planning phase already. Many aspects of the building are concerned by energy issues. In addition to the key components such as façade and building services, the effects on the user, on the indoor environment or on the energy balance of the materials used are energy-related aspects during construction.

The goal of integrated design is to find an optimum solution for the numerous single targets of the project. This shall be achieved at a lower cost than by achieving the single targets independently one after the other.

Therefore integrated design can be used in the new construction as well as in the renovation of buildings. By looking at the different aspects of such an undertaking holistically, different goals can be set into relation and synergies can be utilized (Hofer et al., 2006).

The integrated planning process starts even before the first plan of the building exists (Figure 3). In the initiation phase target criteria are defined which derive from the strategic goals and wishes of the client. These target criteria are based on comprehensive sustainability criteria. However, they can also be prioritized upon certain issues and topics.

The criteria are part of the tender of the designer. Hence, orientation can be given for the first draft, as to how the building is to be designed. When the primary preliminary of the plan is finished, initial testing and optimization steps are performed. Here the plan is tested to see whether the sustainability criteria are met.

At the same time, and in contribution of the overall integrated design team, the building is optimized as best as possible. In this specific case, the focus has been set on energy optimization and its impact on life cycle costs. This applies to both the preliminary and the design. In the preliminary the focus lies on systemic decisions and in design component solutions are to be optimized. The approach for the detailed design was to integrate the already existing solutions and ideas in the tender in such a way, as not to ”lose” issues and requirements that have already been defined beforehand.

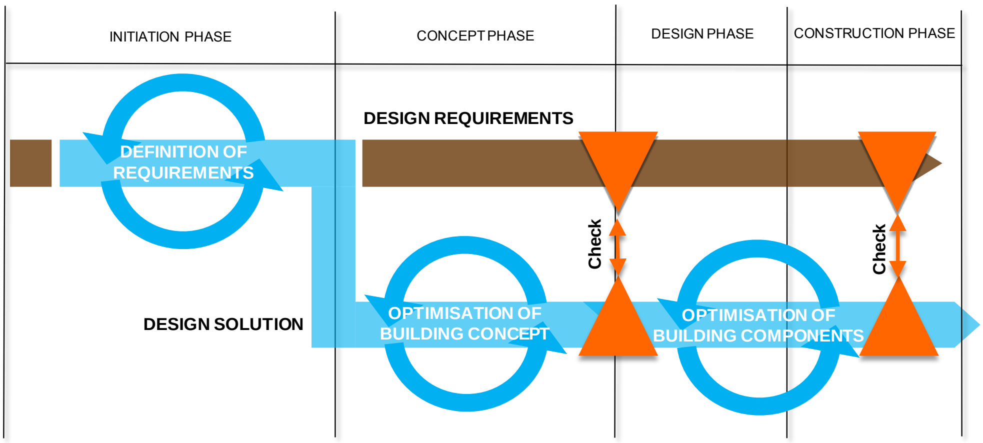

Figure 3: Design phase and activities (Source: M.O.O.CON GmbH, Hofer G. 2011)

4.2 Definition of target criteria

At the beginning of the design process, it is necessary to determine the criteria the building has to meet during at the end of the design phase an in the building use. At the beginning of the design stage of a building project, the client usually has only a rather vague and general idea of his objectives. Therefore, it is essential to translate the client's vaguely stated wishes and goals (strategic goals) into clear and measurable requirements (Von Both 2004, Hofer 2007).These requirements form the basis of the entire design process and can be used in the design competition or the design bid (see Figure 4).

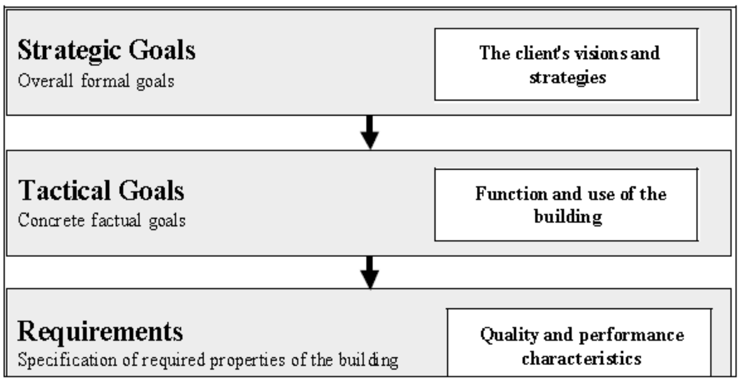

Figure 4: Process of defining requirements (Source: Von Both 2004)

Based on the EU Buildings Directive and the Energy Service Directive, public buildings serve as a showcase action with respect to the economical use of energy. The BIG has set a strategic goal to continue implementing more energetically valuable renovations and thus assume the role model position. Hence, the focus of the target criteria is set on aspects of reducing energy demand and the use of renewable energy systems. At the same time it is essential to look at the building as a whole system instead of solely putting high demands on energy related issues. For instance, a low energy use must not lead to the reduction of user comfort. Therefore, in addition to the existing energy efficiency targets, further ecologic, economic and socio-cultural criteria for refurbishment have been defined.

Since there were no sets of criteria for the renovation of service buildings at the beginning of the project, suitable criteria and requirement levels have been developed on the basis of existing national and international lists of criteria, such as the Austrian sustainability rating systems "Total Quality Building" (TQB) and klima:aktiv, as well as the international system "German Sustainable Building Council" (DGNB) or "BRE Environmental Assessment Method" (BREEAM) for renovation.

In order not to lose the focus on the energy issue, there was no elaborate sustainability certificate used as an orientation for the design process. Hence, energy criteria and further criteria which include the wider energy issues were taken into account.

This also includes the cost of the project in terms of life cycle costs. Thus it shall be shown that projects with lower energy consumption and greater user comfort have little or no impact on the life-cycle costs.

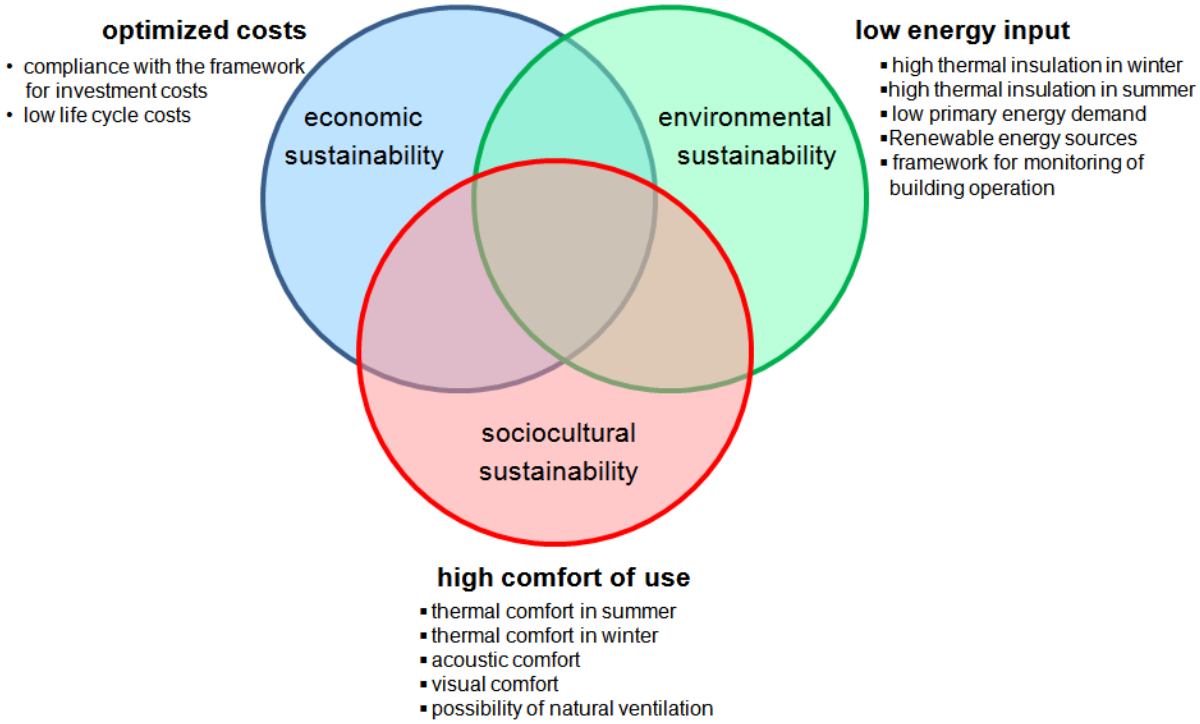

Figure 5: Tactical goals

Based on these objectives, the following set of criteria, which includes criteria, level of requirements and verification methods has been created. It was designed to provide guidance for the general planner throughout the entire planning phase:

economic viability and technical quality of the object

- economic viability
  - calculations of profitability
  - integrated dsign and variant analysis
  - principles for building operation, maintenance and repair

- technical quality of the object
  - air tightness of the building
  - thermal bridges of the building

energy and supply

- energy demand
  - heating demand HWB*
  - cooling demand KB*
  - primary energy demand PEB

- energy efficiency electric power
  - energy efficient lighting
  - solar power system

health and comfort

- thermal comfort
  - thermal comfort in winter
  - thermal comfort in summer

- room air quality
  - ventilation (comfort ventilation with heat recovery, natural ventilation – overnight ventilation)

- soundproofing / room acoustics
  - room acoustics in relevant sections of the building

- illumination, lighting, sun protection and anti-glare shields
  - quality of the artificial lighting
  - supply of daylight / daylight factor / line of sight outwardly
  - sun protection and anti-glare shields

4.3 Supervision of the demonstration projects

After determining the sustainability criteria the BIGMODERN project team accompanied the client and the general planner through the entire design process.

The background of this approach is to identify potential barriers and risks in the implementation of innovative and energy-efficient solutions as quickly as possible and to enable its realization by using suitable information and applying necessary calculations.

On the one hand, the design phase for the demonstration projects within the scope of BIGMODERN was designed to check the abidance of the sustainability criteria with a focus on energy criteria within the design. At the same time, on the other hand, the aim was to optimize the present plan concerning the preliminary as well as the design. Herein the BIGMODERN project team undertook the task of reviewing the compliance of the sustainability criteria. In case of non-compliance with criteria, the client and the general contractor were informed, in order to enable the initiation of a revision of the project.

If additional information or calculations for the realization of innovative solutions were required, these were carried out by the BIGMODERN team, so as to avoid any prolongation of the design process. The optimization of the design was carried out with assistance of the integrated design team. Herein all key stakeholders in the planning of the building were involved: the owner of the building, the general contractor, the tenants and members of the operational management.

Topic related workshops were used for the optimization of the planning process. Additional information from the thermal building simulation and of the life-cycle costing, which accompanied the design, contributed to these workshops. Hence proposals for energetic optimization could be presented, and additionally economic effects could be proven. The result of this was, that essential information for discussion as well as for decision-making are now at hand.

The best possible solution was selected and then carried out in collaboration with the client. Further on the general contractor was supported in the integration of the high-quality design in the tender for the construction project by defining appropriate requirements for the components.

Ultimately the BIGMODERN team revised the tender in the means of quality assurance, for the purpose of maintain all the requirements that were agreed upon.

4.4 Energy optimization

The aim is the joint optimization of the present building and energy concept by investigations of variants.

These investigations of variants are based on the integral design workshop. Within the scope of this workshop, suggestions for improvement are proposed and discussed freely. Thereby, inputs of all stakeholders can be submitted.

In addition to the participants mentioned above, an expert in thermal building simulation should attend the meetings in order to check the possibility of simulating the variants immediately. The eventually defined variants are evaluated using dynamic building simulation. This means that the effects of the variants will regarded with respect to the energy balance of the building as well as the convenience of use. Concerning the ease of use, basically the interior temperatures in summer and in winter are calculated. In addition, the impacts on the supply of daylight respectively the artificial light supply are determined.

4.5 Life cycle costs accompanying the design process

The life cycle cost analysis during the design phase is of paramount importance. Using this method can contribute to bridge the main barriers which impede the implementation of innovative measures. Even though there are arguments claiming that innovative measures are too expensive and not economically anyway, these arguments can be refuted easily.

For instance, by applying design accompanying life cycle cost assessment at a demonstration building, it could be proven that additional measures to conserve energy and to increase user comfort (ventilation in the administrative area, cooling of the courtrooms) causes no extra costs over a time horizon of 30 years. Thus, it was also shown that the measures to improve the sustainability of buildings are economical.

5 Results of the first demonstration project

Within the scope of the BIGMODERN-project, two demonstration projects have been realized, namely the office building in Bruck/Mur and the construction engineer faculty building of Innsbruck University. The refurbishment is already completed as far as the office building in Bruck/Mur is concerned. Regarding Innsbruck University, finally works at the building are done until mid of 2014. In the following, the results of the building in Innsbruck are presented in the following.

5.1 Innovative measures

Based on the results of the integrated planning process, a call for tenders was carried out for the important key measures which are described below:

- Façade: In the renovation-process of the building prefabricated metal cladding panels with high insulation standard (0,12 W/m²K).
- Windows: innovative pivot-hung window, specially developed for the Civil Engineering Building, with automatic control and manual override to increase the natural ventilation and night ventilation.
- Shading: sund-blind between the panes between three slices of low-e glazing and single-disc baffle plate, cost-effective way to open for cleaning and repairing windows and solar shading, radiation -dependent control with individual override the sun protection
- Daylight use: daylight-directing blinds to optimize the daylight entry with sunscreen closed
- Lighting: Dimmable luminaires with daylight and presence-dependent control and an innovative control concept to reduce the lighting time.
- Ventilation: entilation system with rotary heat exchanger for heat and humidity recovery. Innovative, life cycle cost-based ventilation concept using the existing ventilation ducts. In place of the ventilation and conditioning of the aisles inside the building, the injection ports are installed in the offices. Thus it can be cost-effectively provide an improved summer comfort in the use area.
- Cooling: use of a fountain on the grounds of the University for free cooling and for improved system efficiency of the active cooling of the supply air for the building
- Ventilation flaps: Integration of ventilation flaps in the existing partitions between office and transition surface to improve the natural night ventilation. Individual control of air to support the night ventilation
- Control: Innovative control technology concept for the automatic control of the individual sun protection for the reduction of the solar yield, optimization of the window openings of the pivot-hung window for natural night ventilation

5.2 Results of the energy parameters

By carrying out the renovation of the University building Innsbruck, a substantial contribution to the reduction of both the energy input and the CO_2 – emissions is made. The heating demand of the building was reduced from 80 kWh/m²a to 15 kWh/m²a, which accounts for a reduction von 85 %.

Due to the consequent reduction of net energy and the renewal of building services, the primary energy demand could be reduced. In order to increase the user comfort and to reduce heat loss, additional rooms use ventilation system with heat recovery. Hence, there will be some additional energy consumption for ventilation and cooling after the renovation. Nevertheless, the primary energy demand could be reduced by about 75%.

The demo project in Innsbruck proved that a significant improvement in energy efficiency can be achieved. Furthermore, CO2 – emissions were reduced by approximately 75% and the ambitious targets could be achieved.

6 Conclusions

Concerning the implementation of remediation projects with high demands on low energy consumption after renovation and with the aim of low impacts on the life cycle costs, it is essential to apply the integrated design approach. Energy-efficient optimization of a building will only work at the best possible way if there is an interdisciplinary team of technical planners working together. Hence, a good overall approach to the system building can be found. The dynamic building simulation is the appropriate tool to detect vulnerabilities of building plans and to consider suggestions for improvement. Basically, the results of the building simulation serve as input for the integrated design. Thus, all essential information for improving the building with joint efforts shall be provided.

This also applies to the calculation of life-cycle costs. After all, only measures, which are both innovative and energy-saving as well as economically viable over the life cycle can be implemented for the client BIG. Innovative measures often create an advantage in ease of use. These benefits often cannot be displayed monetarily, but they have to be communicated to both the client and the users in order to provide comprehensive information on the effects before making decisions. Moreover it is important that the life cycle costs are calculated accompanying design, so that the results can still have an impact on design. Once the design is completed, the calculation of life-cycle costs can only influence design to a minor extent.

Both the building owner and the tenant should be informed about the construction costs and the future operating costs already at the very beginning of the project, when the building is defined. However, they have to be informed at the latest when the preliminary design is on hand, i.e. when the design of the first plans is accomplished. A comparison of life cycle costs of a standard refurbishment with a modernization of the building by taking high energy efficiency requirements into account is of great importance as it can serve as a basis for decision making.

Only if the tenants understand, that higher investment costs as a result of higher quality standards and lower operating costs are economically reasonable, energy efficient solutions can be put into practice. The impacts on user comfort have to be pointed out within the scope of design. Furthermore, the budgetary constraints of the tenants have to be taken into account.

Within the scope of the demonstration projects, measuring systems for the detailed assessment of energy consumption and the type of use have been installed in the demonstration buildings. Thereby, the results of planning shall be validated by real operational data. Thus, weak spots in the adjustment of the building services systems can be recognized and remedied. This data is also used for the constant energy monitoring of the building.

Based on this experience, the results of the design and the energy monitoring, refurbishment standards for other buildings can be derived. Hence, the BIG will be capable of reinforcing the realization of its goal to implement future renovations with high demands to energy conservation and sustainability.

7 References

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Systemic inefficiencies in retail buildings in Norway

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Abstract

The largest potential for decreasing greenhouse gas emissions, and therewith mitigating the effects of global climate change, comes from improving energy efficiency of existing buildings and communities. Previous research revealed that improvement of energy consumption and a greening of our buildings are not sufficient to cope with the challenges of climate change mitigation. The way we live is tightly connected with the way we buy. Supply of goods is linked to quality of life and needs a rethinking in order to be able meet the challenges of climate change mitigation. An analysis of existing Norwegian retail developments and their impact on local energy consumption is therefore necessary. In this paper inefficiencies of retail industry are examined. Particular focus is placed upon shopping centres within Norwegian urban contexts focusing on technical solutions (ventilation and indoor climate), energy distribution and local production of renewable energy. The results suggest that new procurement measures are necessary in order to be able to develop business models for the building and infrastructure industry that allows a cost effective transition of our built environment. Dynamic building simulation software has been applied and PH criteria for retail building types were developed [1, 2]. Here, detailed criteria for maximum installed power and annual energy use for heating, cooling, lighting, ventilation, and equipment were specified. Also, CO_2 emissions related to the energy used and their implications for building and energy services were introduced. Planning according to described criteria can lead to energy solutions with simplified building services and minimized energy use and emissions

1. Introduction

Energy efficiency of the Norwegian building stock has been pointed out as a major strategy in cutting greenhouse gas (GHG) emissions according to the Kyoto-protocol [3]. The energy consumption of existing office building is rising over the past decade (www.enova.no). In terms of energy consumption today's shopping centers are among the buildings in Norway with the highest energy consumption, with an average of 467 kWh/(m^2a) end energy use. However, rather than suggesting that they are a commercial evil which society can do without, it is suggested here that it is important to work with shopping centres to help create sustainable retail environments which function well within the wider urban structure. On the European level, the principles for the requirements for the energy performance of buildings are set by the Energy Performance of Buildings Directive (EPBD). Dating from December 2002, the EPBD has set a common framework from which the individual Member States in the EU developed or adapted their individual national regulations.

The EPBD in 2008 and 2009 underwent a recast procedure, with final political agreement having been reached in November 2009. The new Directive was then formally adopted on May 19, 2010. Among other clarifications and new provisions, the EPBD recast introduces a benchmarking mechanism for national energy performance requirements for the purpose of determining cost-optimal levels to be used by Member States for comparing and setting these requirements.

The previous EPBD set out a general framework to assess the energy performance of buildings and required Member States to define maximum values for energy delivered to meet the energy demand associated with the standardized use of the building.

However it did not contain requirements or guidance related to the ambition level of the directive. As a consequence, building regulations in the various Member States have been developed by using different approaches (influenced by different building traditions, political processes and individual market conditions) and this has resulted in different ambition levels even though in many cases cost optimality principles could justify higher ambitions[4]. Figure 1 shows measured and temperature corrected delivered energy and net energy demand according to building regulations in different building types.

The passive house (PH) concept is a successful measure to reduce energy use in buildings. It has been applied in many projects in Europe, especially in Germany and Austria. In Norway the attempt was made to describe the PH concept in a new building code [1] [5] [6].

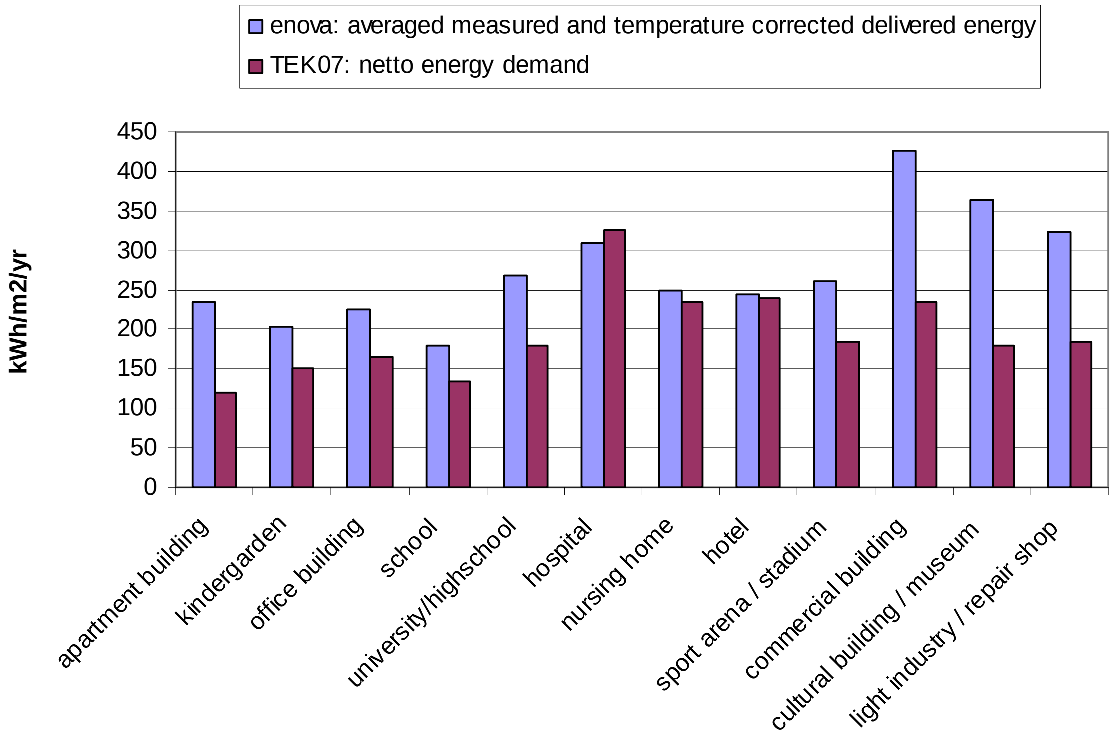

Fig.1. Measured and temperature corrected delivered energy and net energy demand according to building regulation (including heating, cooling, ventilation, lighting, appliances) in different building types.

2. Objectives

In this paper the goal was the development of a framework for the transformation of shopping centres that reduces greenhouse gas emissions. For this purpose inefficiencies of retail industry are examined. Particular focus is placed upon shopping centres within Norwegian urban contexts focusing on technical solutions (ventilation and indoor climate), energy distribution and local production of renewable energy. The PH concept is introduced and discussed in relation to the existing building codes. Here, detailed criteria for maximum installed power and annual energy use for heating, cooling, lighting, ventilation, and equipment are specified. Passive house criteria retail building types have been developed. CO_2 emissions factors related to the energy used and their implications for zero emission buildings are discussed.

3. Method

In this paper inefficiencies of retail industry are examined. Particular focus is placed upon shopping centres within Norwegian urban contexts focusing on technical solutions (ventilation and indoor climate), energy distribution and local production of renewable energy. The results suggest that new procurement measures are necessary in order to be able to develop business models for the building and infrastructure industry that allows a cost effective transition of our built environment [2]. Dynamic building simulation software has been applied and PH criteria for retail building types were developed. Here, detailed criteria for maximum installed power and annual energy use for heating, cooling, lighting, ventilation, and equipment were specified. Also, CO_2 emissions related to the energy used and their implications for building and energy services were introduced. From existing buildings that are considered for renovation or even transformation the existing building regulations (in Norway TEK) have to be followed [10]. TEK follows closely the methodologies introduced by EPBD. Another possibility is following the Norwegian standard for low energy and passive buildings NS3701 [2] [7] [8]. The buildings were equipped with different energy supply options, starting from an "all electric" grid solution (which is typical for Norwegian office buildings from the 80ies), going through some options for the heating system (while electricity comes from the grid), to more hybrid solutions. Delivered energy as well as GHG emissions from operation and production phase were compared and evaluated.

3.1 Data analysis

Starting from the average energy consumption in shopping centers and shops of 467 kWh/(m2 a) a survey including the biggest shopping center owners revealed that there is a large spread in specific energy consumption in shopping centres and shops in Norway. Figure 2 shows energy consumption of shopping centres in orange bars and shops in blue bars. It can be seen that some shopping centres use less than 100 kWh/(m2 a) while others use up to 2600kWh/(m2 a). The average figures for shopping centres is 310 kWh/(m2 a). It can further be seen that some shops in Norway use less than 100 kWh/(m2 a) while others use up to 2700 kWh/(m2 a). The average for shops is 510 kWh/(m2 a).

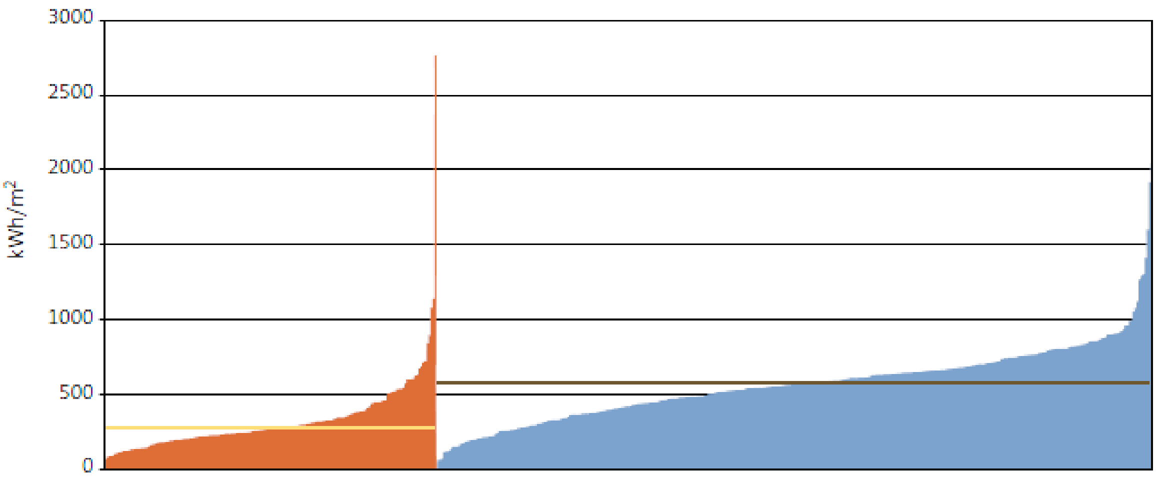

Figure 1: Energy consumption data of shopping centers (orange bars) and shops (blue bars) in Norway [9]

A reference case has a measured delivered energy of 321 kWh/(m2 a) with district heating system. The energy frame for new constructions (as well as for major renovation projects) is 210 kWh/(m2 a) (TEK10). The building regulation is going to be reviewed by 2015 where even more ambitious requirements are expected. Shopping centres are often a mix of functional pattern with areas dedicated for office, (hotel and) restaurant and wholesale and retail services [9].

3.2. Minimum requirements

For Norwegian building code compliance either minimum requirements have to be fulfilled and documented. Alternatively, if the net energy demand for the building, calculated according to the methodology established in the new Norwegian Standard NS3031 (2007), is within the energy frame for the building's category, the regulations are also satisfied [5]. Here, a holistic approach ensures accounting for all building energy needs. Since the frame is based on net specific energy demand per year, the efficiencies of the energy systems are not taken into account. This means that for example the coefficient of performance of a highly efficient mechanical cooling system is not rewarded.

Table 1. Minimum requirements.

characteristics	**TEK07**	**passive house**
U- value walls	≤ 0.18 W/(m^2·K)	≤ 0.15 W/(m^2·K)
U- value floor	≤ 0.15 W/(m^2·K)	≤ 0.15 W/(m^2·K)
U- value roof	≤ 0.13 W/(m^2·K)	≤ 0.13 W/(m^2·K)
U- value windows[a]	≤ 1.20 W/(m^2·K)	≤ 0.80 W/(m^2·K)
U- value doors	≤ 1.20 W/(m^2·K)	≤ 0.80 W/(m^2·K)
Normalized thermal bridge value, Ψ"	≤ 0.03 W/(m^2·K)	≤ 0.03 W/(m^2·K)
System efficiency heat recovery, ηT [b]	≥ 70 %	≥ 80 %
SFP-factor ventilation system	≤ 2.5 kW/(m^3/s)	≤ 1.5 kW/(m^3/s)
Air leakage at 50 Pa, n50	≤ 2.50 h^{-1}	≤ 0.60 h^{-1}

[a] incl. frames
[b] annual mean temperature efficiency

Passive measures that reduce the net cooling demand will contribute to satisfy the energy frame which has led to a renewed interest in utilizing passive measures to decrease the total energy use in all building types. However, there are still minimum requirements concerning the U-values and air tightness of the building envelope which help to maintain a good insulation standard. These are listed Table 1 above [10].

3.3. Average air volume and internal loads

The holistic approach mentioned above led to a new evaluation of internal loads and minimum values for ventilation, all divided into the functional pattern of typical shopping centres. Table 2 shows maximum allowable internal loads in passive house standard [2].

Table 2. Internal loads.

building type	**lighting**	**equipment**	**occupants**	**internal gains (average)**
	W/m²	W/m²	W/m²	W/m²
Office	5	6	4	5.4
Hotel and restaurant	5	1	2	6.0
Wholesale and retail services	11	1	7	8.1

Table 3 gives the average airflow requirements during and outside operation. It can be seen that airflow during operation ranges between 6 (offices and hotels) and 12 m³/(hm²) (retail buildings).

Table 3. Average airflow requirements.

building type	**average airflow**	
	during operation	outside operation
	m³/(hm²)	m³/(hm²)
Office	6	1
Hotel and restaurant	6	1
Wholesale and retail services	12	1

3.4. Annual energy demand for heating and cooling

Table 4 shows the maximum allowed figures from the passive house standard [1,2] for energy demand, heat loss factor, and CO_2 emissions. It can be seen that maximum heating demand ranges between 15 (offices) and 20 kWh/(m²a) (hotel and retail)). Maximum cooling demand ranges between 10 (office and hotel) and 20 kWh/(m²a) (retail).

Table 4. Maximum allowed energy demand, heat loss factor, CO2 emissions according to [1;2].

building type	annual energy demand		Heat loss, H''	CO_2-emissions, m''
	Heating	Cooling		
	kWh/(m²a)	kWh/(m²a)	$W/(m^2 \cdot K)$	$kg/(m^2 \cdot a)$
Office	15	10	0.5	25
Hotel and restaurant	20	10	0.65	40
Wholesale and retail services	20	20	0.65	40

3.5. Overall heat losses

Normalized overall heat loss is defined by heat losses through the building envelope, heat losses through ventilation and infiltration and calculated for heated floor area. Table 4 shows the results for proposed maximum values [7]. Heat losses range between 0.5 (offices) and 0.65 W/(m2·K) (hotels and retail). Maximum allowed CO_2 emissions range between 25 (office) and 40 kg/(m2·a) (hotel and retail).

3.6. Delivered energy and CO_2 emissions

In order to evaluate the CO_2 emissions of a building from its operation CO_2 factors of the delivered energy are needed. Proposed CO_2 factors are shown in Table 3. This requires in addition the adjustment of net energy demand to delivered energy. Here, the efficiency of a heating and/or cooling system needed to be considered [5]. Table 3 gives an overview of the energy supply options studied (for heating and electricity with ventilative cooling), their efficiency and CO2 emission factors (of the energy carrier) according to [7].

Table 3. Efficiency and CO_2 factors for different energy supply options.

option	Heat source	Efficiency [-]	CO2 emission factors [kg/kWh]
1	Electricity	0.98	0.395
2	oil boiler	0.73	0.330
3	gas boiler	0.73	0.277
4	heat pump	2.11	0.395
5	50% district heating, rest electricity	0.84	0.231
6	district heating	0.84	0.231
7	50% DHW solar thermal, rest electricity	8.55	0.395
8	50% DHW solar thermal, rest heat district heating	8.55	0.231
9	biofuel boiler	0.84	0.014
10	CHP with biofuel, covering heating and DHW	0.84	0.014

4. Results

4.1. Climate

The influence of different climatic conditions was analyzed. The results are shown in Figure 3. Heating and cooling demand varies considerably with lowest heating demand in Stavanger (4.3 kWh/(m^2 a) and highest in and Karasjok (46.3kWh/(m^2 a)) while lowest cooling demand is in Røros with 4.8 kWh/(m^2 a) and highest in Oslo (14.4 kWh/(m^2 a)).

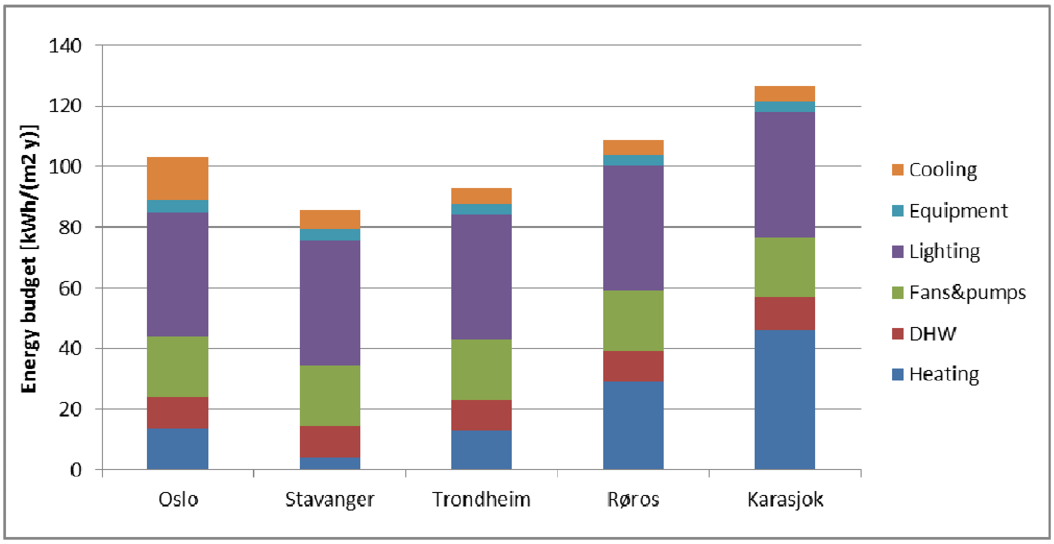

Figure 3. Energy demand in different climates in Norway

4.2. Thermal comfort

Figure 4 shows a selected south-facing room / shop of 96 m², which is simulated (solar and internal gain) for the assessment of thermal comfort. Shadows / shading from building projections, nearby buildings, vegetation or horizon is not taken into consideration. It is considered the use of effective exterior shading (light blinds). Ventilation is considered in the hottest periods with 15 m³ / m² h, and installed cooling power is 20 W / m² (ventilation cooling). The store is medium weight, with a normalized heat capacity of 67 Wh / m² K. With these measures are maximum operating room temperature of 26.1 º C is assured as shown in Figure 5.

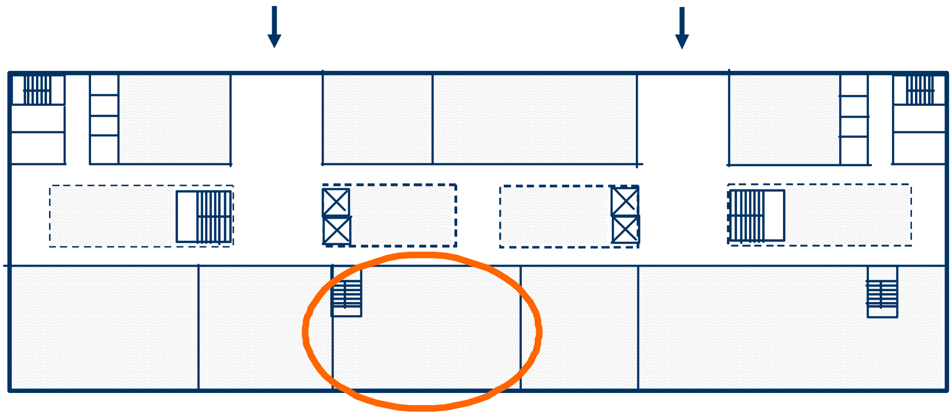

Figure 4. Plan solution of model with south-facing room / store with 96 m² simulated under design summer conditions.

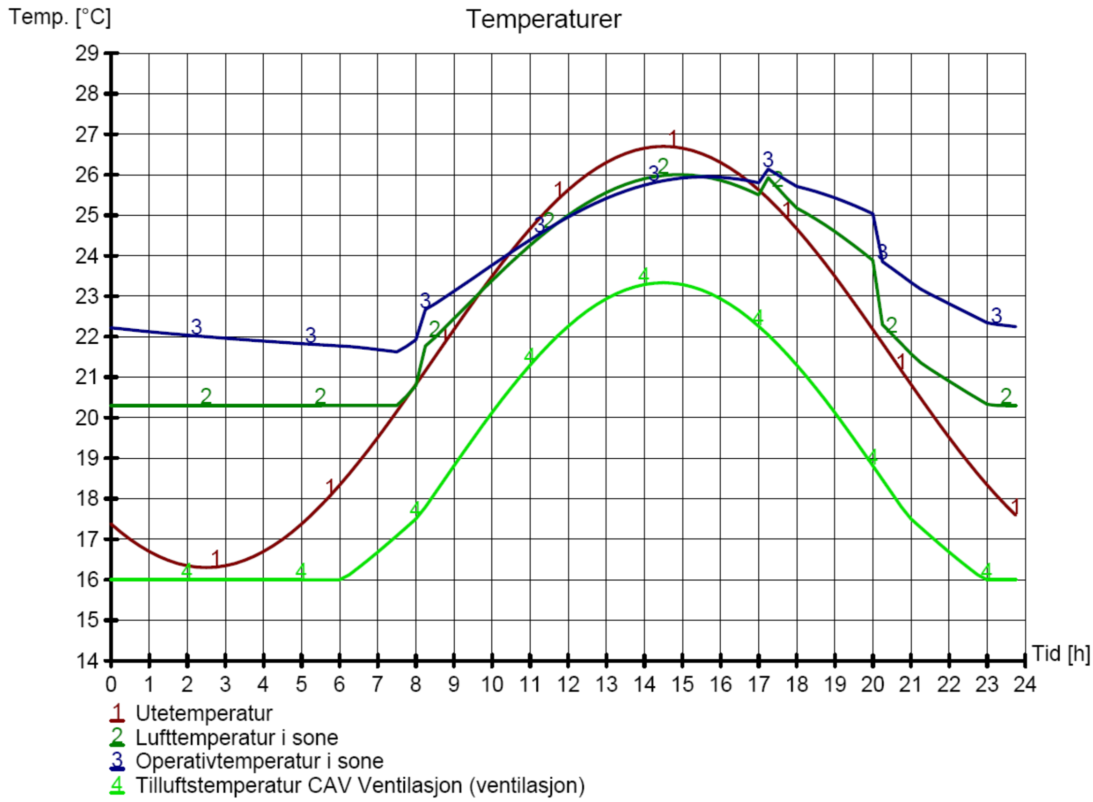

Figure 5. Simulated temperature distribution for a store under typical summer conditions. Calculations were done with simien [5]

4.3. Delivered energy and energy labeling

Different energy supply options have been evaluated and results were compared. An evaluation of the design with respect to the above mentioned concepts is possible through building simulation based on NS3031 [4]. For this purpose Simien was used [5]. The potential for greenhouse gas emission reductions was evaluated. It can be seen from figure 6 that different energy supply options have a good potential for energy efficiency, i.e. reducing delivered energy to the building. The levels of delivered energy for three different energy labels (A, B, and C) are also given. It can be seen that changing the supply option alone is not sufficient to achieve energy label C. For the current building code (TEK) not all supply options secure energy label C and none label B (except the heat pump option in the Hotel category). On the other hand does the Passive house level (PH) reach in almost all supply options energy label A (except in the retail category where only HP and solar thermal collectors for DHW (50%) are sufficient).

Figure 7 shows the results of the CO2 emissions from operation for different building categories, construction level and supply option. The green lines illustrate maximum CO2 emission levels that have been proposed [7]. When it comes to GHG emissions it can be seen in that the buildings with low energy concept (PH) show very low emissions. Even if those buildings are equipped with conventional energy supply system this can result in lower emissions than existing buildings with renewable energy supply (e.g. biofuel boiler). It shows also that e.g. equipping an existing building with a biomass boiler reduces more GHG emissions than refurbishing the existing building to TEK with a heat pump.

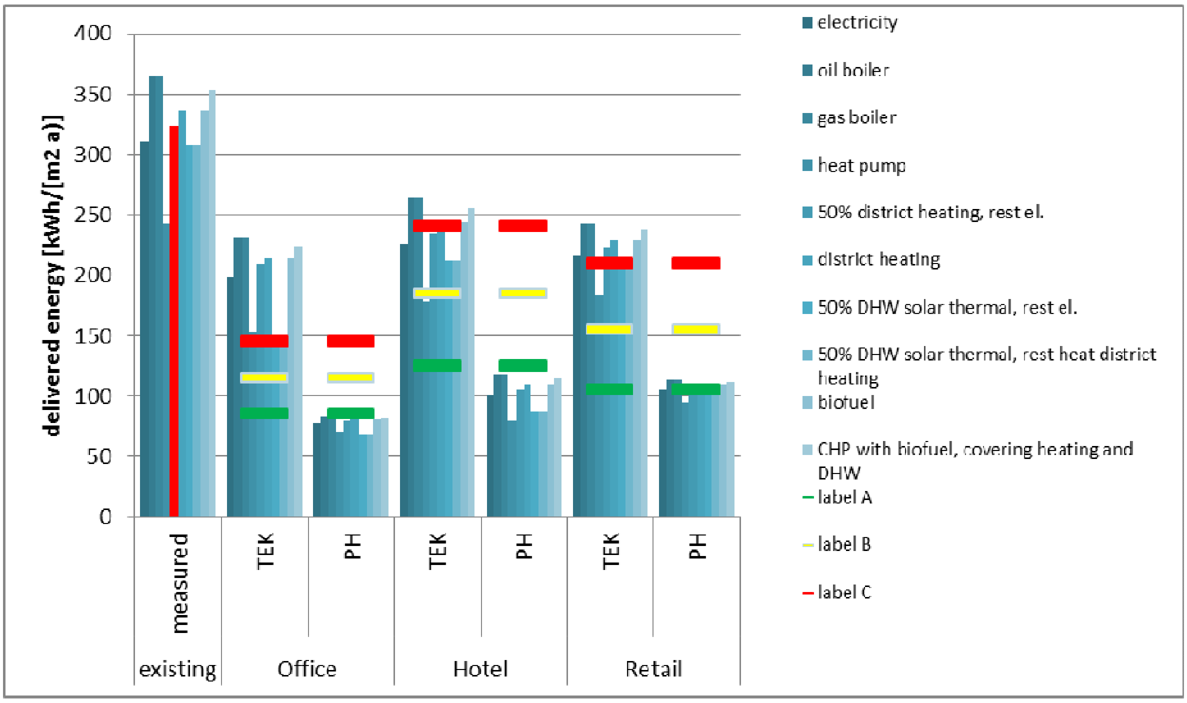

Figure 6. Delivered energy and energy label for Oslo climate

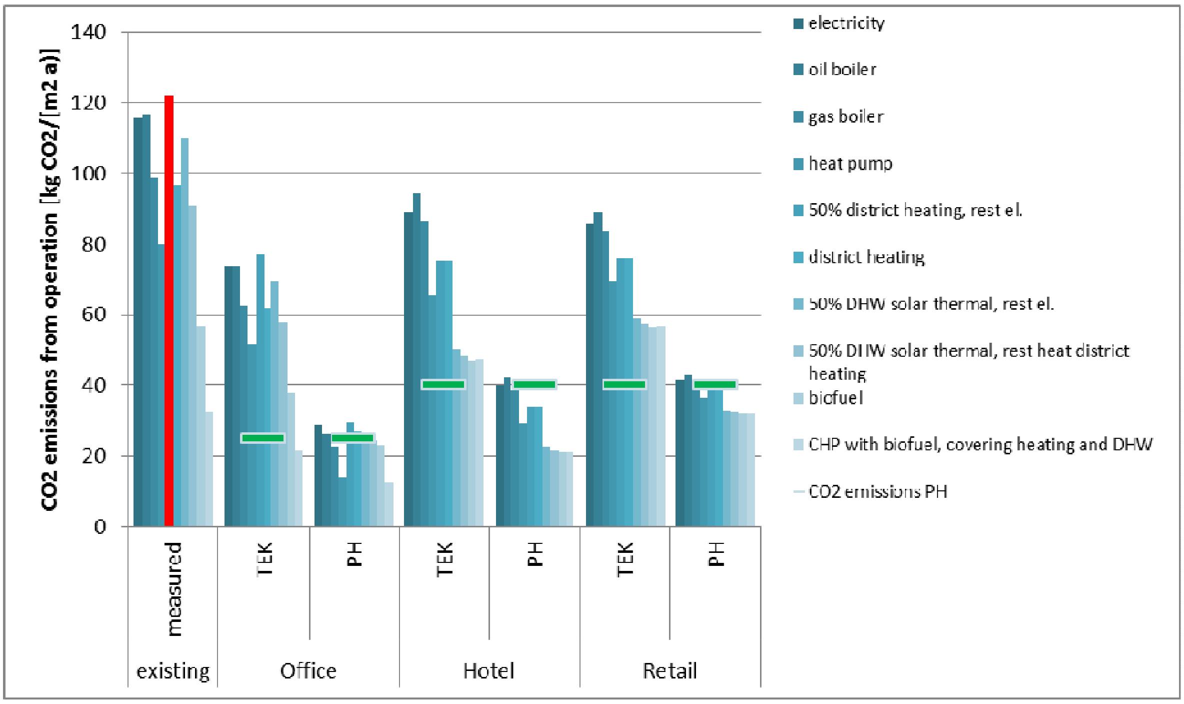

Figure 7. CO2 emissions from operation for Oslo climate

5. Conclusion

The PH concept is a good starting point on the conceptual path to minimizing building energy use and CO_2 emissions. The PH criteria for retail buildings show small but important differences in the minimum requirements. Especially improved requirements for air tightness needs a careful design and detailed planning. Here, the building sector needs more support and information on predefined construction solutions.

The purpose of this study was to develop a framework for the transformation of shopping centres. The potential for decreasing GHG emissions, and therewith mitigating the effects of global climate change, through the improvement of the energy efficiency of existing buildings and communities is an important step in a sustainable transformation. While previous research revealed that improvement of energy consumption and a greening of our buildings are not sufficient to cope with the challenges of climate change mitigation a framework was presented that reduces greenhouse gas emissions and is linked with the role of shopping centres and their typical functional pattern.

From an existing shopping centre with three functional pattern (office, hotel and restaurant, and retail) the standard building construction (TEK) as well as the Norwegian passive house standard (PH) was applied to the building. The total energy consumption in the case study was minimized with different measures. Different construction levels with different levels of energy efficiency, different levels of heating demand were analyzed. Different energy supply systems were compared with respect to delivered energy and GHG emissions.

Maximum allowable heat loss factors will ensure a building construction quality which is a prerequisite to be able to build buildings with minimum CO2 emissions. Thus, planning according to described criteria can lead to cost effective buildings and energy solutions with simplified building services and minimized energy use and emissions. In the non-residential sector with more complex building services, and with an increase in delivered energy there is an increased need for such criteria. In order to minimize energy use and CO_2 emissions it seems appropriate to further link decisions on suitable energy supply systems with regard to related CO_2 emissions. It is essential to consider low emissions and energy efficiency at the start of the renovation phase and to establish key targets. Ambitions and intentions should be stated in the building program, containing a finite number of clear and manageable high level objectives. Objectives regarding building suitability, energy demand and building materials should be emphasized and put into specific terms. Emission targets should be related to functions rather than technologies.

The results show that some renewable energy supply applications could be more effective than ‘energetic’ refurbishment. The level of local community integration (and commitment) is of special importance (with regard to local renewable energy system size and local district heating distribution). Furthermore, the integration of solar applications into facade and roof refurbishment could further help to find the maximum possible renewable energy supply on-site that could determine the level of building construction (energy and costs) concept in the renovation process.

A cost effectiveness analysis comparing refurbishment costs with renewable energy supply system applications should be added. In addition, GHG emissions from operation and production phase must be compared and evaluated. The social component put together from user integration, comfort, and living quality (also on community level) is an important part in sustainable refurbishment projects. We have to acknowledge that the way we live is tightly connected with the way we buy. Supply of goods is linked to quality of life and needs a rethinking in order to be able meet the challenges of climate change mitigation.

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Designing Self-Energy Sufficient Buildings in India

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Abstract

The presented research work focuses on the utilization of alternative sources of renewable energy, mainly solar energy, for satisfying the energy demand in buildings. One such possibility is through Building Integrated PhotoVoltaics (BIPV) and improving energy efficient features through passive solar design in the buildings. The research team has studied two design cases, an existing building of 2011.12 m^2 and a new building of 100 m^2 ground area suitable for BIPV installation in Central Gujarat region of Western India. The paper includes literature review on type of field data required, parameters for energy efficient buildings, and estimation of solar energy generation on buildings, techno-economic analysis and feasibility of BIPV. The team's analysis on both cases reveal that BIPV retrofitting in existing building is found to be expensive over designing a building with BIPV as pre-thought. Also BIPV modules produced excellent architectural form and enhanced overall aesthetics of the building. The BIPV as pre-thought has been found to be cost effective since they just not act as energy producer, but also reduces the cost of building materials it replaces. Taking into consideration, the multi-beneficial nature of BIPV, we estimate the pay-back period to be 5-15 years depending upon the type of connection (Grid-connected or Stand-alone), amount of energy replacement by BIPV and the existing Government policies and incentives. (WC = 215)

Keywords: BIPV; Building energy; Economic Payback; Retrofitting; Gandhinagar

1. Introduction

With the recent economic and industrial development and GDP growth rate reaching about 7.4% in India [1], it has come out as major energy consumer among the developing countries globally. According to the Government of India, Ministry of Statistics and Programme Implementation, the per capita energy consumption has increased almost four-folds in four decades during 1970-2010 year. But in a period of 1980-2010 during last three decades, India's annual energy consumption has increased five-folds (4 quadrillion Btu to 22 quadrillion Btu) [2]. This owes to the improved urban living standards and advanced means of energy consumption from households to industrial sector.

Nomenclature

I	Irradiance on given surface [kWh/m^2/day]
A	Area required [m^2]
l	Loss factor
D	Energy demand [kWh]
E	Energy generated by PV panels [kWh]
Ah	Ampere hours
Units	kWh
kWp	Kilowatt peak
Greek letters	
η	Efficiency of PV panels [%]
Subscripts	
Req	Required

Buildings in India generally are responsible for at least 30-40% of energy use and this demand is growing annually at 11-12%, which is almost twice the average electricity growth in the economy which is 5-6% annually [4]. GRIHA manual [1] cites that there is an increased demand of about 5.4 billion units of electricity annually for residential and commercial buildings. In a typical building, approximately 80-90% of the energy is consumed for heating, cooling, lightning and other appliances

[5]. The other 10-20% is utilized during construction and material manufacturing. Apart from being a leading energy consumer in the infrastructure sector, buildings are also prime generators of Green House Gases (GHG), thus posing a threat to the environment. Globally, the urban areas contribute 70% while the housing construction and estate development contribute 40% to the GHG emissions. Buildings contribute approximately 50% of the world's air pollution, 42% of GHG emissions, 50% of water pollution, 48% of solid waste and 50% of CFCs (chlorofluorocarbons) to the environment [1]. This is an alarming issue which needs to be addressed by developing energy efficient building design which would facilitate minimization of energy consumption and will spur sustainable growth. On a macro-view, buildings in India are seldom designed to reduce the embodied and operational energy. Trends are rising on reducing the water needs and technologies to recycle used water for secondary usage are getting implemented. Still, the energy issue remains unaddressed. Energy efficient building design in India on a macro-scale can prove to be the most promising option since the building sector has the largest potential for reducing GHG emissions significantly.

2. Literature review

BIPV has emerged as a principal source of energy with excellent integration as building element. BIPV has not only been considered as energy producer technology but also as building material for enhancement of the building aesthetics. S Wittkopf et al 2008 [7] presented design of BIPV in Singapore's first Zero-energy building at Building Construction Authority. It provided guidelines for integration as multifunctional behaviour of PV was assessed. They studied feasibilities of installation sites including skywalk, walkways, and parking lots. The results of the estimated PV production were compared with the demand and were found to be encouraging. In recent research study by S N Tabriz et al 2011 [8], they integrated architectural design with BIPV system, thus proposing reforms in the planning side with BIPV as pre-thought. Emphasis has been laid on designing houses that supports human health and provide natural heating, cooling, ventilation and insulation along with BIPV systems. John Byrne et al 2001 [9] in their research studied performance of Mono- and Poly-crystalline PV modules in Shanghai, China calculating the PV value, cost and payback period. They have considered rooftops and curtain walls for installation of PV modules. Analysis is done on a hypothetical location for thin film and polycrystalline PV modules. Emphasis is laid on multi-tasking of BIPV and payback period is estimated to be less than five years. K. Kurokawa 2001 [10] in their paper on grid-connected PV systems for studies on residential, commercial and industrial buildings. It concentrates on centralized connections having 1 MW PV plant installed on tops of the residencies in Bremen, Germany. Commercial buildings provide potential on facade installation whereas industrial buildings support installation on roof, wall and parking spaces and street lights on roads.

3. Methodology

We have adopted solar passive design and BIPV for self-energy sufficient building while optimizing the demand for day-lighting and heating. Thus, a combination of both components not only ensures enhancement in energy efficiency but also paves the way for net-zero energy building. The parameters considered for designing are potential site, climatic condition along with technical and socio-economic status of the user. It is to be noted that potential site for installation refers to the site which is exposed maximum to solar irradiance during the day and it is least affected by shadowing. It includes site location (latitude and longitude), orientation and area of the potential site. Climatic conditions include solar irradiance corresponding to tilt and azimuth of the site. Socio-economic status include prevailing energy demand for existing building and anticipated energy demand based on occupancy for new building, capital investment, Government subsidy and feed-in tariff and payback period. Technical status includes market availability of PV panels and suitable Balance of System (BOS) affects the economy and size of PV array. Design is also affected by the choice of grid-connectivity of the system i.e. off-grid or grid connected.

3.1 Formulae used in calculation of energy generation, estimation of required area and cost

It is assumed that the BIPV installation will meet the total energy demand for entire building. The 3-types of BIPV panels have been selected based on their suitability as building material viz. efficiency of 15.35% for Multi crystalline C-Si panels with 250 Wp, 10% for Multi crystalline BIPV modules (Glass-to-Glass laminates) with 135 Wp and 7% for Multi crystalline A-Si thin Film panels conventional PV panels with 85 Wp. As per prevailing market survey, it is presumed that mounting, accessory cost, and labour cost will be 25% of the total cost [11]. The other factors are DC-to-AC Derate factor is 0.7 (worked out based on Indian conditions); 30% Government subsidy up to 1kW for residential installation and up to 100kW for institutional and commercial installation [12]; Feed-in tariff is Rs. 11.57/kWh fed in the grid for 25 years for the period of April 1, 2013 to March 31, 2014 [13]; energy cost of Rs. 6.5/kWh.

3.1.1 Calculation of required area for PV installation

The area requirement for PV has been calculated using an iterative process. First the maximum energy demand is calculated/ forecasted based on primary building survey and BIPV area is calculated considering the minimum solar irradiance on the south facing surface having latitude tilt using eq. (1). Then through iterative process required area for BIPV installation is compared with available actual area available on the potential site. The priority surfaces available for solar installation in decreasing order have been sunshade, skylight, rooftop and finally façade. This iterative process will stop once area required is equal to or less than available area for BIPV. The irradiance data used for the calculations of area and energy generation over various components is provided by IWEC [14].

$$A_{req} = D/(I \times \eta \times l) \qquad (1)$$

3.1.2 Calculation of estimated energy generation when the area for installation is known

Energy generation estimation is based on solar irradiance on the corresponding surface, efficiency of the selected PV panel, DC-to-AC Derate factor and area available over the potential site. Thus the energy generated is given by

$$E = I \times \eta \times l \times AI \times \eta \times l \times A \qquad (2)$$

3.1.3 Calculation of Battery size

Battery size is calculated based on installed capacity, hours of battery operation and the battery voltage available as given in eq. (3). It is to be kept in mind that battery size is generally taken 20-25% more to ensure sufficient and anticipated future demand fulfilment.

Battery size (Ah) = (Installed capacity × Hours of operation)/Battery voltage (3)

3.1.4 Calculation of Payback period

Payback period depends on the net cost, annual savings and annual earnings. This paper does not include cost of building material being replaced by BIPV panels and accelerated depreciation mechanism for payback cauculation.

Payback = Net cost/(Annual Savings + Annual Earnings) (4)

3.1.5 Prevailing market price of PV Panels and BOS in Indian market used for cost calculation

The prices of PV panels based on market survey undertaken by the research team during April-May 2013 have been found to Multi crystalline BIPV module 135 Wp (Rs 70 /Wp); Multi crystalline C-Si module 250 Wp (Rs 80 /Wp); Multi crystalline A-Si Thin film module 250 Wp (Rs 45 /Wp); Inverter (Rs 7.5 /Wp); and Battery (12V, 100Ah) of Rs. 10,000 per unit.

4. Analysis and Discussion

This research paper has analysed the potential of BIPV and passive solar design for two building types in and around Gandhinagar city. The first case displays an institutional building at Pandit Deendayal Petroleum University (PDPU) campus SPT-1 having a plinth area 2111.12 m^2; and the second case is a virtual residential building having plinth area of 100 m^2 in Gandhinagar city. The first case relates to retrofitting using BIPV while the second case exhibits a combination of passive solar design and BIPV to demonstrate maximum energy efficiency.

4.1 Retrofitting of SPT-1 building of PDPU using BIPV

The SPT-1 building in the PDPU campus consists of 10 class-rooms, 9 laboratories, library, faculty wing, offices and the reception area. A survey had been done by the research team to collect the building drawings, existing energy demand and physical features of the building. The building orientation is 30^0 west of south; direction of the façade wall is east; length of façade wall is 98.225 m; the wall is exposed to 4.81 kWh/m^2 solar irradiance on vertical surface on an average in January with an exposure of 6 hours; the area exposed to sunlight on façade wall is 1028.4 m^2 with openings accounting for 471.65 m^2; plantation in the front of the wall is up to a height of 2.92 m and shadow almost the ground floor; the building's main energy consumption is from 09:00 hrs to 18:00 hrs i.e. for 9 hours daily. During the analysis, it has been found that the building has its longest side having a length of 98.22m due east orientation. Some plantation is done up to the height of ground floor on the east façade of the building. The class-rooms are located on this wall and thus major aspects are on this wall. This side provides possible PV installation on walls, windows and the sun-shades; the South face of the building is 34.9 m long. The major concern is the shadowing due to the dense canopy trees on this wall which restricts the available area for PV installation; 37% of the façade area on the West elevation is available for the installation and rest 63% is under shadow.

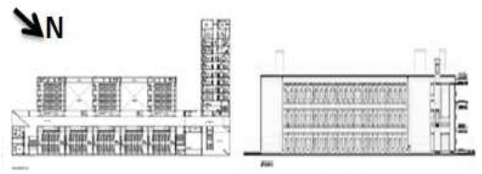

Fig. 1. (a) Plan and (b) Front elevation of SPT-1 building [15]

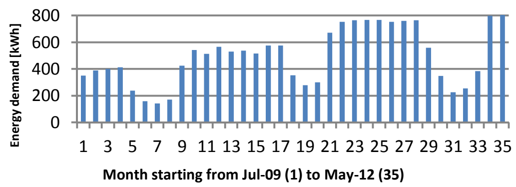

Fig. 2. Energy demand of SPT-1, 2 building from July - 09 to May – 12 [15]

The average daily demand from July-09 to May-12 has been collected from Amenities and Logistics Department of PDPU Gandhinagar. The electrical consumption has increased four folds as it can be seen from Figure 2 [13]. The trend can be attributed to increase in occupancy, increased use of high voltage appliances. Furthermore it can also be inferred from the figure that the energy demand is less in the months of November to January and is high in the months of March to September. The high electrical demand of the SPT-1 buildings calls for the use of alternate sources of energy based on the renewable sources. BIPV system is selected as an alternate energy source to replace full or partial demand of the total demand.

4.1.1 Calculation of energy generation on various sites on Façade wall

Based on the area calculated from building plan and elevation, potential solar sites available on the various components of the façade wall such as sunshades, adjacent walls and windows have been considered for installation. The energy consumption in the period of July 2011 to June 2012 has been selected for the purpose of calculation. Thus, the energy generated from potential sites will be compared with average daily demand as shown in Para 6.1 above. Table 1 shows position of installation, average irradiance and type of panels used.

Table 1. Features of selected sites of SPT-1 building

Site	Area available [m^2]	Position of installation	Average irradiance [kWh/m^2/day] [14]	Types of panel used [11]	Dimensions of panel [m] [11]
Sunshade	168.65	At 67° w.r.t vertical	5.96	Multi crystalline C-Si 250	1.65x1
Adjacent wall	280.6	Vertical	3.40	Multi crystalline C-Si 250	1.65x1
Window	314.44	Vertical	3.40	Multi crystalline BIPV 135	2x1

Table 2 shows the average daily consumption of SPT-1 building during various months. The minimum consumption is witnessed in the months of January having 278kWh followed by February 300kWh while maximum consumption of 768kWh is being witnessed in the months of July and June respectively.

Table 2. Average daily consumption of SPT-1 building [15]

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Demand [kWh]	768	754	760	765	560	348	278	300	671	752	764	768

Table 3 shows the comparison of area required and the area available on sunshade, adjacent walls and window based on the calculation done using eq. (1). The maximum area available for BIPV installations has been 46.8% of total required area for installations. Therefore, total energy demands of SPT-1 building from BIPV installations are not being met. It shows the remaining unsatisfied demand after each installation under column 2. However, it is to be noted that sunshade has a reduction potential of 17.29%, adjacent wall has a reduction potential of 16.43% and window has a reduction potential of 11.99%. It is also to be noted that although installation area is 36.17% of the total built-up area, it replaces 45.71% of the total energy consumption.

Table 3. Calculations for required area and % demand satisfied by each site

Site	Maximum demand unsatisfied [kWh]	Area required for installation [m^2]	Area available for installation [m^2]	Reduction potential [%]
Sunshade	768.00	1631.85	168.65	17.29
Adjacent wall	683.55	3420.22	280.6	16.43
Window	627.47	6884.73	314.44	11.99
Total			763.69	

Daily average of energy generated by BIPV on available area of 763.67 m^2 has been calculated using eq. (2). The daily energy generation is shown in Table 5. The calculation of CO_2 emission is done using online calculator provided by www.carbonify.com which considers that saving one kWh of energy saves 8.9 g of CO_2 [16]. The cost and payback period has been based on Solar Power Policy (2009), Government of Gujarat on subsidy and incentives (feed-in tariff, acceleration depreciation benefits) for Solar Photovoltaic kilo-watt scale installation [17].

The present installation replaces 45.71% of the energy demand. The total area under installation from Table 3 is 763.69 m^2 which is 36.17% of the total area on the facade replaces 45.71% demand. It can be seen from figure 3 that the production exceeds the demand in the months of January and February thus providing surplus production. In the rest of the period of the year the demand exceeds the production. Since the time for which the solar power is available is in synchronization with the period of peak demand and the production is less than the demand for major period of the year, the production is utilized on site thus eliminates the use of battery bank reducing the economy.

The CO_2 emission is reduced by 30.47% which thus justifies BIPV as a means to reduce the GHG emissions due to buildings' energy usage. The reduction in CO2 emission is found to be high in the months of May to August which also helps in reducing in reducing the surface temperature if seen on a macro level. The average reduction is minimum in the month of December. Table 4 and 5 shows the cost and economic details related to the BIPV installation at SPT-1 building using costs as stated in para 5.1.5. In addition to it, price for individual component, prevailing government subsidy on renewable energy installation the payback is calculated using eq. (4). However use of Accelerated Depreciation (an incentive provided by Government of Gujarat) in the calculation of payback period, it can be furthermore reduced endorsing its feasibility.

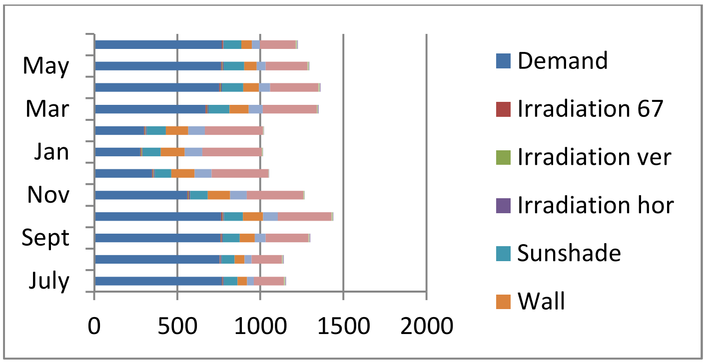

Fig. 3. Year round energy demand, energy production for different sites and CO_2 emission

Table 4. Installed capacity and cost of PV panels

Site	Area [m^2]	Number of panels	Installed Capacity [kW]	Cost/Wp [Rs.]	Cost [Rs.]
Sunshade	168.65	102	25.5	70	1785000
Adjacent wall	280.60	171	42.75	80	3420000
Window	314.44	158	21.33	45	959850
Total	763.69	431	89.58		6164850

Table 5. Total cost and Payback

Item	Panels	Inverter	Mountings, etc.	Labour cost	Gross total	Government Subsidy[12]	Net total	Annual savings	Annual earnings	Payback [years]
Cost	61.64	6.71	13.67	6.83	88.10	26.66	62.21	6.42	0.45	8.70

4.2 Design of a residential building with BIPV as a pre-thought

BIPV as a pre-thought has been considered for designing a hypothetical residential building of size 10m x 10m in Gandhinagar. The goal has been to design a residential building which can satisfy the total energy demand as well built-design is aesthetically appealing. The important parameters considered are building orientation (180 degree north); proper positioning of aspects and openings to maintain ambient built environment throughout the day. Outdoor plantation in the veranda has been recommended to reduce the ground reflectance thus ensuring day lighting with comfort w.r.t indoor temperature. BIPV has been the pre-thought element for the building design for satisfying the energy demand and also to replace certain building elements thus reducing the cost of building material that it will replace. Looking on to the building, few elements which include Façade, Sunshade on the 1st floor, Skylight and roof stand out as promising potential sites for installation. The highlighted potions show the selected potential sites for installation.

Table 6 shows the dimensions of the potential sites selected, their area and the panels selected for the installation. Sunshade enjoys the priority for the freedom that it provides for both- tilting and selection of panel. Skylight is a new concept for Indian buildings which has been selected for demonstration of BIPV as replacement of traditional roofing material. Thus, BIPV modules have been used. BAPV Roof installation has gained attention in India but BIPV using thin film is still a new idea and thus it has been promoted. Finally, façade restricts the choice of tilting and the choice of panel also. Thus BIPV modules have been selected replacing the wall. During the survey of 450 buildings including residential, commercial and institutional buildings conducted by the research team during May-2013, energy demand for households in a part of Gandhinagar city was collected. The energy demand shown in Table 7 has been projected based on the analysis of the survey data. It can be seen from the table that the energy demand experiences a sudden increase in the month of May and June. It is attributed to the increase in the cooling load in summer.

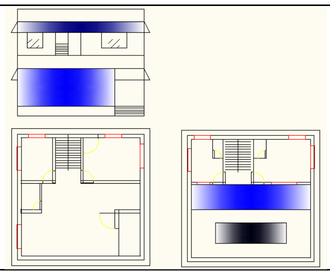

Fig. 4. Schematic plan and elevation of hypothetical residential building

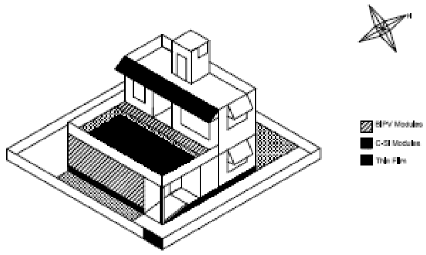

Fig 5. 3D isometric view of the proposed building

Table 6. Dimensions of the selected sites and panels used

Site	Dimension [m]	Area [m^2]	Panels used
Sunshade	10x1	10.00	Multi crystalline C-Si 250
Skylight	8x1	8.00	Multi crystalline BIPV 135
Roof	4x2.5	10.00	Multi crystalline Thin film 85
Facade	6x2	12.00	Multi crystalline BIPV 135

Table 7. Year around monthly demand used for calculation

Month	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Demand [kWh]	123	123	191	191	407	407	293	293	254	254	178	178

Table 8. Required area, available area and % demand satisfied by each installation

Site	Maximum demand unsatisfied [kWh]	Area required [m^2]	Area available [m^2]	Reduction potential [%]
Sunshade	407.25	28.78	10	80.84
Skylight	220.93	24.87	8	38.65
Roof	115.09	18.50	10	29.76
Facade	33	10.41	12	35.40
Total			40	

The design of BIPV system involves required area calculation which is done using eq. (1). The calculation of the required area has been done using the model discussed in Para 6.1.1. Table 8 shows the comparison of area required and the area available on the potential sites. It shows the reduction potential of each site (%) and also the demand that remains unsatisfied after each installation. Sunshade has the reduction potential of 80.84%, skylight has the reduction potential of 38.65%, Roof has the reduction potential of 29.76% and façade has the reduction potential of 35.40%.

Thus the installation on all of the selected sites yields to completely satisfying the energy demand and having some surplus. Monthly energy generation is calculated using eq. (2). The results are displayed in figure 6.

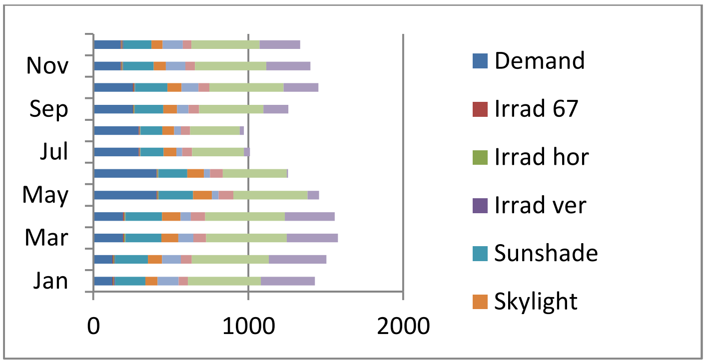

Fig 6. Year round energy demand, energy production for different sites and CO_2 emission

Thus the results shown in figure 6 justifies the installation as the demand is met round the year and also surplus energy is produced which can be fed to grid or can be used for secondary use or communal use. BIPV system produces surplus throughout the year but exactly matches the demand in the month of June. The maximum surplus occurs in the month of January to April while the entire demand has been secured. It is also noted from Table 11 that 40% of the total built-up area covering the suitable sites entirely covers up the total energy demand when it is decided to have BIPV from the design stage itself. The CO_2 emissions due to energy usage have been reduced to zero.

Table 9 and 10 shows the cost and economic details related to the BIPV installation on the residential building. Size of Battery backup is calculated using eq. (3). The cost of various units has been used from Para 5.1.5. In addition to it, price for individual component, prevailing government subsidy on renewable energy installation the payback is calculated using eq. (4).

Table 9. Installed capacity and cost of PV panels

Site	Area [m^2]	Number of panels	Capacity [kW]	Cost/Wp [Rs.]	Cost [Rs.]
Sunshade	12	6	1.00	80	80000
Skylight	8	4	0.54	70	37800
Roof	10	6	0.51	45	22950
Facade	10	6	0.54	70	56700
Total	40	22	2.86		197450

Table 10. Total cost and Payback

Item	Panels	Inverter	Battery	Electrical accessories	Labour cost	Gross total	Subsidy	Net total	Annual savings	Annual earnings	Payback [years]
Cost	1.97	0.22	1.19	0.51	0.34	4.23	1.27	2.97	0.19	0.28	6.29
All units in Rs Lacs (Rs 100 = US$ 1.63 as on 06 Oct 2013)											

5. Conclusions

In this research study, two cases have been compared. One; BIPV retrofitting and two; building with BIV as pre-thought. The analysis shows that it is better to design a building with BIPV as a pre-thought against retrofit on an existing building. The later found to be more expensive since it restricts the choice of potential sites and positioning the panel. However, a new design provides an opportunity for suitable building orientation which is impossible while going for retrofitting. An energy production and optimisation model has been developed for the calculation of the required area for BIPV installation. The priority for available surfaces varies from sunshade, skylight, rooftop and façade in decreasing order. The cost and payback period has been based on Solar Power Policy (2009), Government of Gujarat on subsidy and incentives (feed-in tariff, acceleration depreciation benefits) for Solar Photovoltaic kilo-watt scale installation. The solar power policy found to be favourable to the installers/ user leading towards up-scaling the growth of solar installation in the state. The solar policy has reduced the payback period significantly and comes out to be less than 7 years for a residential and less than 10 years for an institutional building without availing accelerated depreciation. Furthermore, we find that BIPV technology is promising technology to reduce CO_2 emissions as reduction in the emissions by 30.47% have been possible in the case of retrofitting and have been eliminated in the new design. Finally, we conclude that BIPV is a promising technology and has the potential to reduce the energy crisis across the country and is also a justifiable means for CO_2 emission reduction thus escalating sustainable growth.

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Case Study

COMFORT EVALUATIONS DURING SYDNEY'S HOTTEST DAY EVER @ 45.8 DEG C

Ashak Nathwani[1]

ABSTRACT

Sydney Australia has been in the news more recently due to the early onset of warm weather resulting in bushfires with devastating outcomes. Sydney also experienced some heat wave conditions earlier last year. On 18 January 2013 Sydney had its hottest day ever. The mercury reached 45.8 degrees Celsius in the Central Business District (CBD). One high rise building maintained surprisingly reasonable comfort levels in spite of the fact that the conditioning system was never designed to handle such ambient conditions or indeed the associated heat wave conditions. The building, built in 2005, is prominently positioned in the Sydney's financial core. This A-Grade property offers 31 levels of commercial office space, a specialised retail offering and parking. The building incorporates a Variable Air Volume air conditioning system with variable speed drives and VAV boxes with terminal re-heat coils. The air handling units are located at mid-level and top level plant rooms. Central plant, namely chillers, boilers and cooling towers are at roof level plant room. State-of-the-art Building Management System (BMS) maintains the pre-set temperature conditions on each floor, in each of the zones.

It was coincidental that Comfort Analysis was under way in this thirty (30) stories building as part of a research project by the University of Sydney. The methodology involved use of latest technology in the form of I-Buttons located in each of the perimeter and interior zones, which were placed on the underside of work stations on three levels of this building. Comfort measures, Predicted Mean Vote (PMV) and Predicted Percentage (of People) Dis-satisfied (PPD) evaluations were carried out. As defined by ISO 7730 there is a direct correlation between PMV and PPD whereby when the PMV is plus or minus 3, 100% of a group will be dis-satisfied. At zero PMV, when the indoor conditions are "perfect", it is predicted that at least 5% of any group will still be dis-satisfied. This takes into consideration the "human" factor associated with comfort.

The results of the study on this hottest day showed that whilst perimeter zones experienced higher indoor temperatures at different times of the day, the Interior Zone, which accommodated the majority of the occupants, maintained indoor temperatures between 22 and 24 degrees C – giving comfort values in the form of PMV, ranging from – 0.5 to – 0.4 with corresponding PPDs of 5 to 8%. This is indicated in the graphs.

Achievement and subsequent maintenance of such comfort levels was only possible due to actions taken by the Facility Management team. Many of the steps taken on that day or prior to that day have been developed into longer term strategies that also enable optimisation of energy consumption.

Keywords: Indoor environmental quality; PMV, PPD, energy consumption, Sydney's hottest day ever, FM energy saving strategies

INTRODUCTION

Australian cities, including Sydney, have been in the news more recently due to the early onset of hot weather resulting in bushfires with devastating outcomes. Sydney experienced heat wave conditions earlier in 2013. On 18th of January 2013 Sydney had its hottest day ever. The mercury reached 45.8 degrees Celsius in the Central Business District (CBD). One high rise building maintained surprisingly reasonable comfort levels in spite of the fact that the conditioning system was never designed to handle such ambient conditions or indeed the associated heat wave conditions. The building, built in 2005, is prominently positioned in the Sydney's financial core. This A-Grade property offers thirty (30) levels of commercial office space, a specialised retail offering and underground parking.

There was a research project by the University of Sydney underway in some of the buildings including this one, whereby temperature and humidity data was being recorded in this thirty (30) stories building. The research involved a study to investigate comfort in various buildings with different types of air conditioning systems. The methodology utilized latest technology, in the form of I-Buttons, which were located in each of the perimeter and interior zones. For this building they were placed on the underside of work stations on three (3) different levels. Further data was gathered subsequently and discussions were held with the Facility Managers of this building to specifically review the procedures that they had adopted that enabled the building to maintain reasonable comfort conditions on this hottest day that Sydney had ever experienced.

THE BUILDING

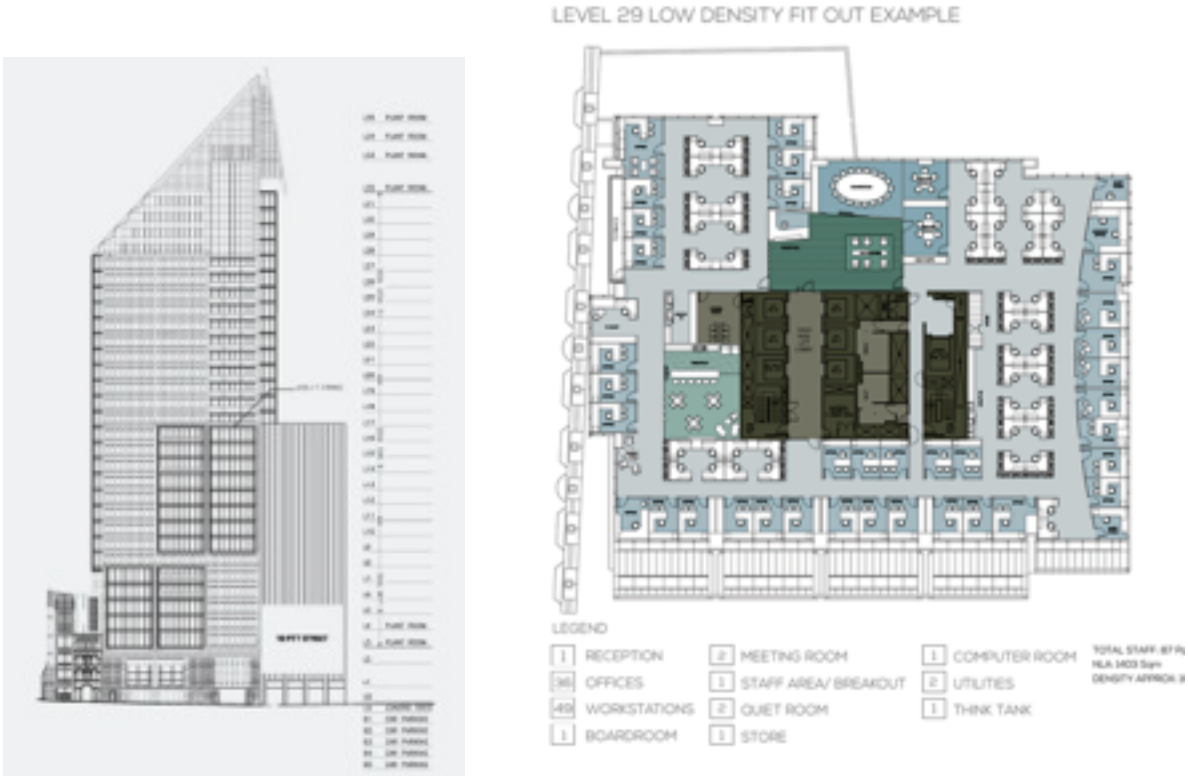

Fig 1 – Building Section & Floor Fit Out Example

Fig 2 – South Face - Outlook

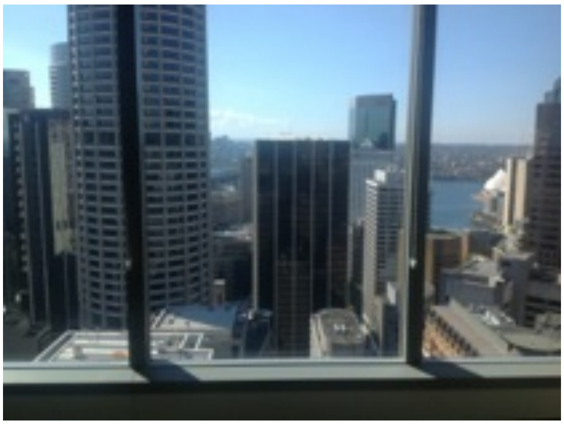

Fig 3 – North Face - Outlook

Fig 4 – West Face - Outlook

Fig 5 – East Face - Outlook

The building incorporates a Variable Air Volume air conditioning system with variable speed drives and VAV boxes with terminal re-heat coils. The air handling units are located at mid-level and top level plant rooms. Central plant, namely chillers, boilers and cooling towers are at roof level plant room.

COMFORT PARAMETERS

Fanger"s PMV model uses four environmental variables, air temperature, relative humidity, air velocity and mean radiant temperature MRT, in addition to two personal variables, clothing insulation and metabolic rate. These variables are used as inputs to predict the mean comfort vote of a group of subjects on the ASHRAE seven points thermal sensation PMV scale (Fanger, 1970).

International Standard, ISO 7730 defines comfort using Predicted Mean Vote (PMV) and Predicted Percentage (of People) Dissatisfied (PPD) as the measure. This is expressed as follows;

$$PMV = (0,303e^{-2,100 \cdot M} + 0,028) \cdot [(M-W) - H - E_c - C_{res} - E_{res}]$$

where the different terms represent, respectively:

M - the metabolic rate, in Watt per square meter (W/m^2);

W - the effective mechanical power, in Watt per square meter (W/m^2);

H - the sensitive heat losses;

E_c - the heat exchange by evaporation on the skin;

C_{res} - heat exchange by convection in breathing;

E_{res} - the evaporative heat exchange in breathing.

$$PPD = 100 - 95 \cdot e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)}$$

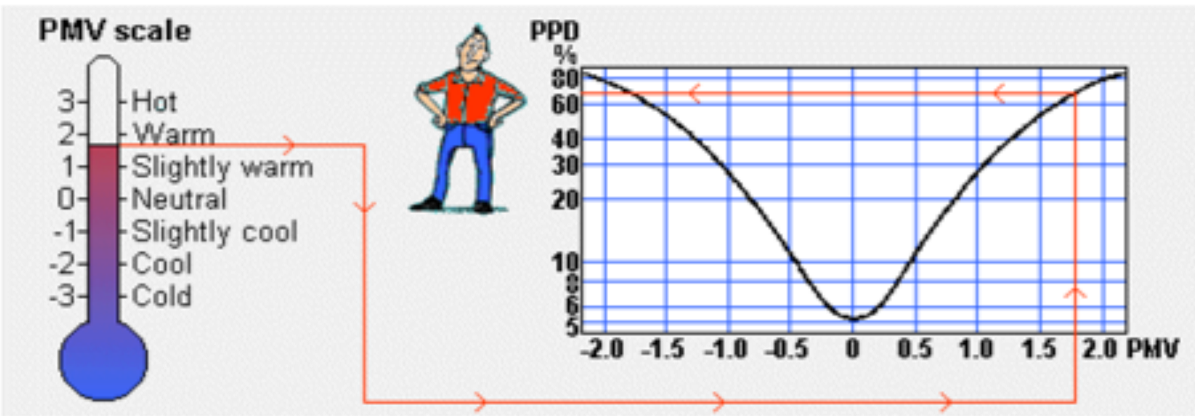

Fig. 6 – PMV – PPD Relationship

This highlights a direct correlation between PMV and PPD, whereby when the PMV is plus or minus 3, 100% of a group of occupants in an environment will be dissatisfied. At zero PMV, when the indoor conditions are “perfect”, it is predicted that at least 5% of any group will still be dissatisfied. This takes into consideration the “human” factor associated with comfort.

Some researchers argue that poor measurement of clo value and metabolic rate caused the differences between measured and predicted mean votes in real field studies (Brager et al, 1993; de Dear, 1998; de Dear and Brager, 1998; Parsons, 2001; de Dear, 2002; Humphreys and Nicol, 2002). But perhaps most importantly, the adaptability factor affected the output of the model in field studies (Brager and de Dear, 1998 and 2000) because it is a psychological parameter that could not be prevented nor estimated.

Humphreys and Nicol (2002) have questioned the validity of PMV model in every-day normal life. According to them, “*PMV predicts the mean comfort vote of a large group of people exposed to the same thermal environment, wearing clothes having the same level of insulation, and all having the same level of activity. This circumstance rarely, if ever, occurs in practice... How then can PMV be tested against these data?”*(Humphreys and Nicol, 2002, p.669). However from a comparative point of view the PMV and PPD model can be applied and this is the approach taken for this case study. It is interesting to note that the level of complaints (or lack off) did “validate” the outcomes – though no formal evaluation was carried out though any questionnaires.

PRACTICAL ANALYSIS

Fig 7 – I-Button

For air temperature and humidity, I-Buttons were employed.

It is to be noted that each I-Button has the capacity to record temperature and humidity values every fifteen (15) minutes for a period of up to three months. With these recordings it was possible to evaluate comfort.

I-Buttons were placed, underside work stations, in the Interior and Perimeter Areas of three floors in this building – Levels 30, 19 and 6. The data was collected over two months – January & February 2013.

With regards to Clothing, a value of 1.2 Clo has been estimated as an average value.

Similarly the activity which translates in to the metabolic rate (Met) has been taken as 1.15 – typical of an office type environment..

Subsequently there were other tests carried out to measure the air velocity at workstation level in the various locations. This was carried out during the warmer periods when the VAV air conditioning system was providing the appropriate air quantities in each of the zones. The average air velocity was 0.21 m/s.

Radiant heat – particularly from the Perimeter Glass has an impact on the PMV. The radiant temperature evaluation was carried out using the Infrared Digital Camera – once again on a subsequent occasion and the outcomes were used to estimate values for the hottest day

Following are some examples of the thermographs:

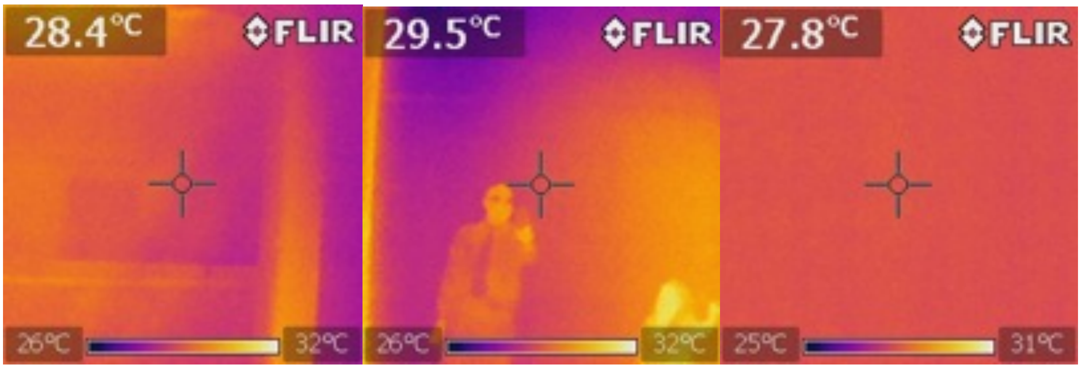

Fig 8 – Digital Camera Thermographs

RESULTS:

Results were used from the three floors to calculate the PMV and the associated PPD for each of the Zones. The software used for these calculations is readily available on the internet. Graphs are presented below for L 30, which is the most exposed with no shading from adjacent buildings.

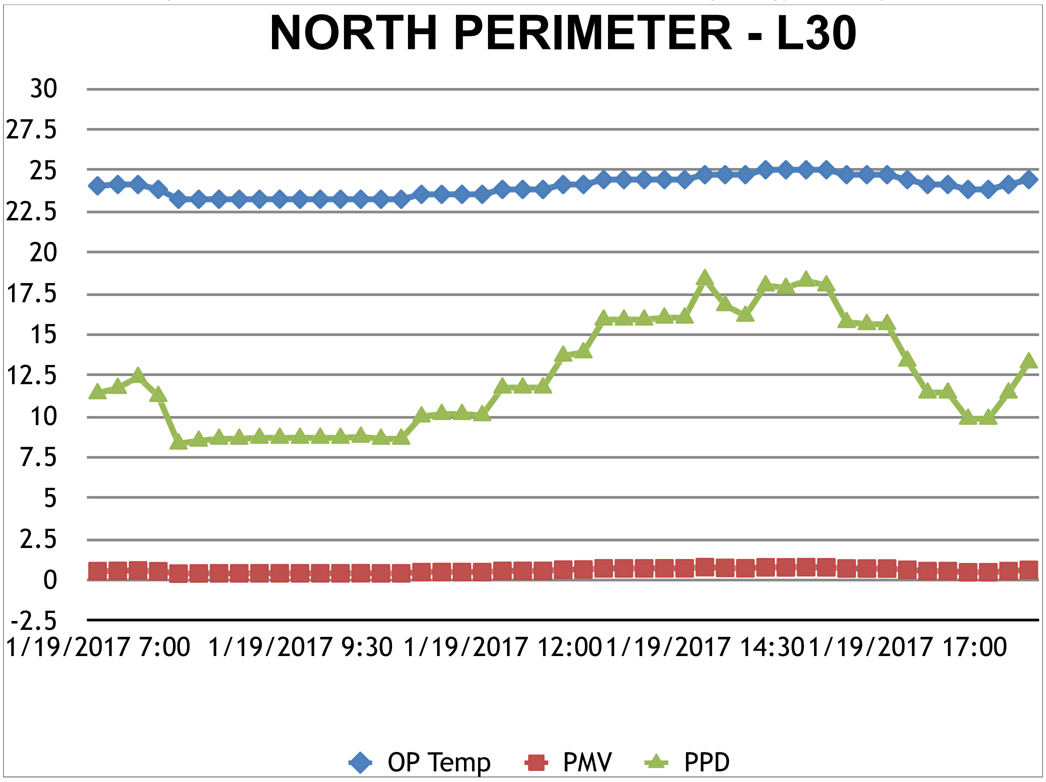

Fig 9 – Graph - Hottest Day – Operative Temperature (OP), Predicted Mean Vote (PMV) & Predicted Percentage Dissatisfied (PPD) - NORTH

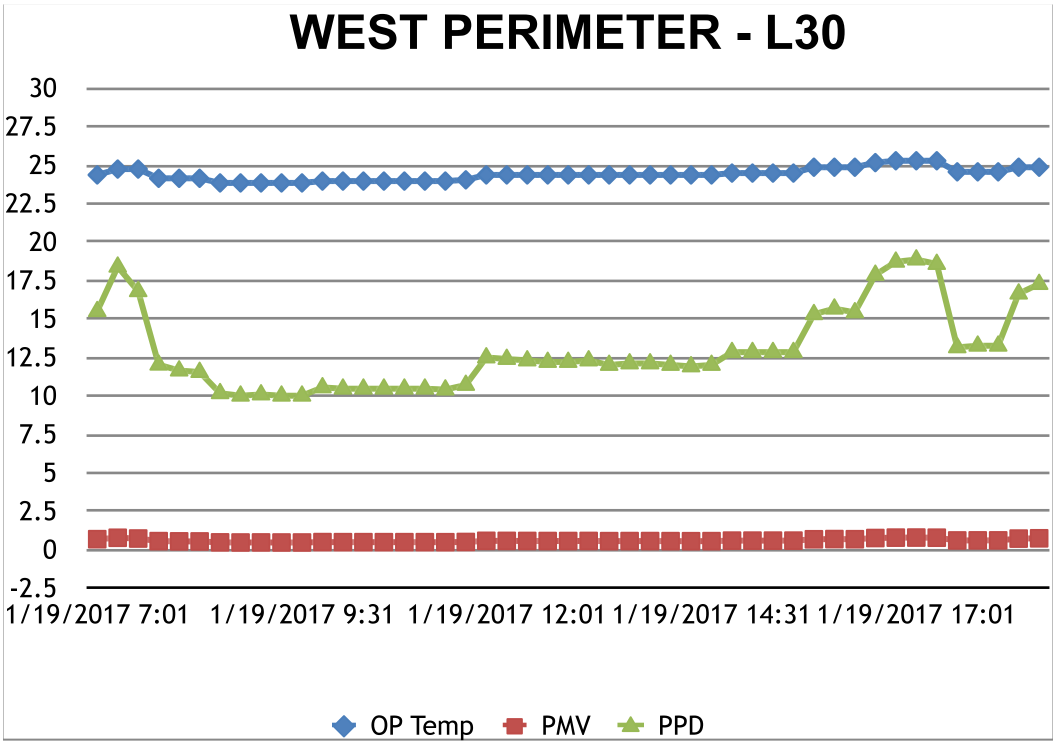

Fig 10 – Graph – Hottest day - Operative Temperature (OP), Predicted Mean Vote (PMV) & Predicted Percentage Dissatisfied (PPD) - WEST

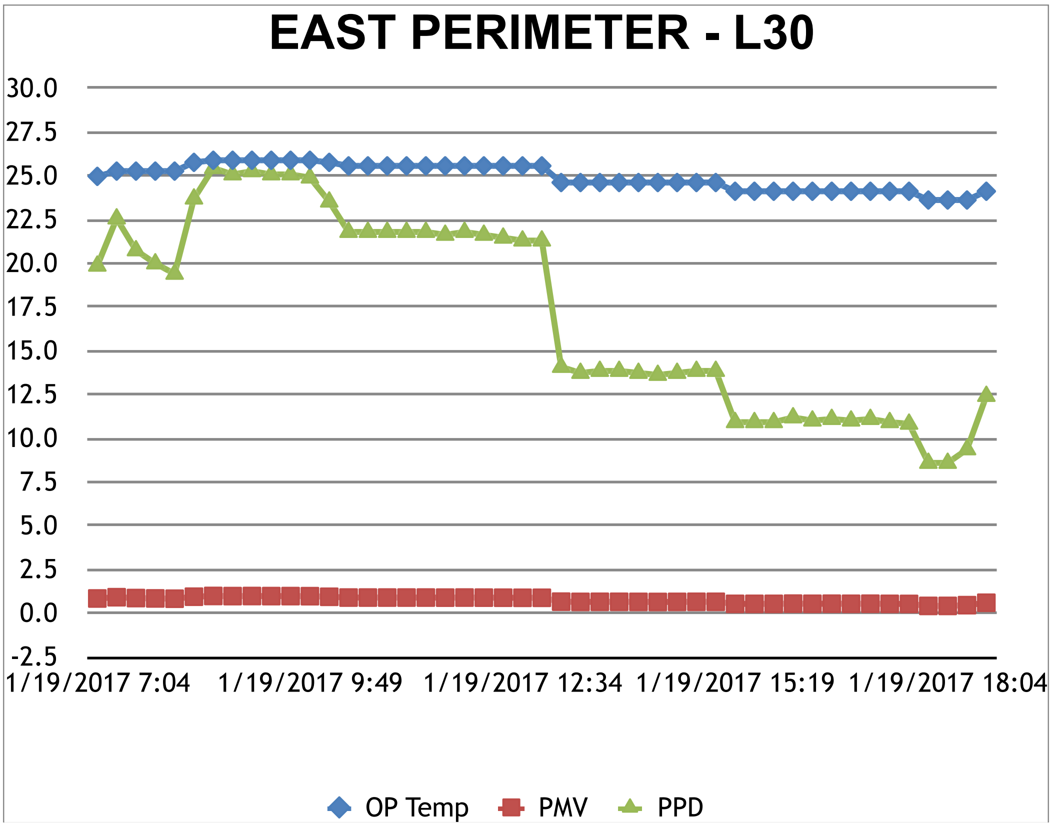

Fig 11 – Graph – Hottest Day - Operative Temperature (OP), Predicted Mean Vote (PMV) & Predicted Percentage Dissatisfied (PPD) - EAST

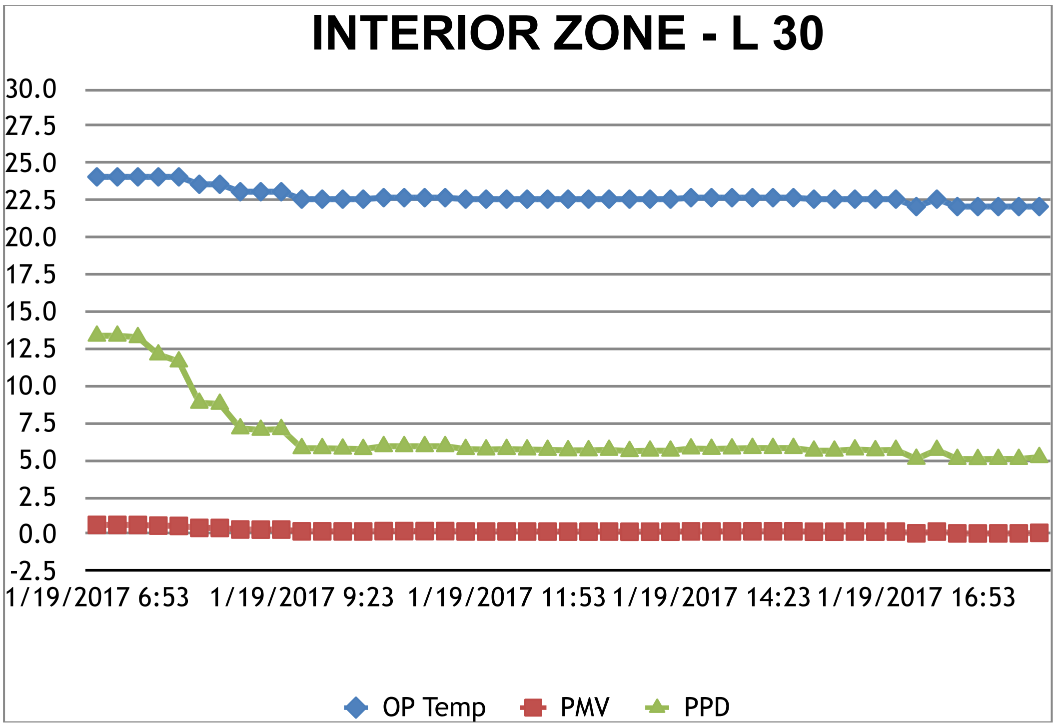

Fig 12 – Graph – Hottest Day – Operative Temperature (OP), Predicted Mean Vote (PMV) & Predicted Percentage Dissatisfied (PPD) - INTERIOR & SOUTH

ANALYSIS

The results of the study on this hottest day showed that whilst perimeter zones experienced higher indoor temperatures at different times of the day, the Interior Zone, which accommodated the majority of the occupants, maintained indoor temperatures between 22 and 24 degrees C – giving PMV values ranging from – 0.5 to – 0.4 with corresponding PPDs of 5 to 12%, as indicated in the graphs above.

The key areas of higher PPD values in the respective perimeter zones were due to Radiant Temperature component – which was minimized with blinds drawn.

FACILITY MANAGEMENT ACTIONS

Achievement and consequent maintenance of such comfort levels was only possible due to actions taken by the Facility Management team. Many of the steps taken on that day or prior to that day have been developed into longer term strategies that also enable optimisation of energy consumption.

The Facility Managers for this building had been monitoring the heat wave conditions in January and had prepared an action plan. First of all, they communicated with all the tenants by advising them of simple actions they could take like wearing suitable clothing during this unusually hot spell. It was noticeable that wearing appropriate summer clothing reduced the clothing or "clo" value (from typically 1.2 to 1.05), which is one of the parameters of the comfort equation. Secondly, they advised those occupants located in the perimeter zones to keep the manually operated window blinds down, especially during the times when there was the potential for direct sunlight ingress, like the eastern side in the morning and the western areas in the afternoon. Thirdly, they dimmed or turned off the perimeter lights using the integrated Building Management System (BMS), where appropriate, to cut down on the heat output from the lights. Fourthly, using the BMS, it was ensured that all the reheat features of the Variable Air Volume system had been locked out. Fifthly CO2 sensors in the return air ducts ensured that only the right amount of fresh air was being introduced via the air conditioning system. Mid-January is still a time for summer (and school) holidays and hence the building occupancy was not up to its full capacity. Thus the fresh air quantity was relatively less. Taking into account the high ambient temperatures, this measure assisted significantly in reducing the demand on the cooling system. Lastly the Facility Managers had made sure that maintenance had been carried out on all cooling equipment such as chillers and cooling towers, in spring – well in advance of the warmer temperatures.

During the days before the hottest day, the BMS was utilised in monitoring the ambient temperatures and starting the cooling system earlier than normal. On this day, for example, the air-conditioning was left on all night and this 'pre-cooled' the building before the arrival of the occupants. This is evident in the graphs.

Throughout the day, the facilities management team was actively monitoring indoor conditions (after all, buildings are built for people to be comfortable, thereby enhancing their productivity) and kept all occupants informed of prevailing external as well as internal conditions. This communication went a long way.

After the success of achieving reasonably comfortable indoor environment on the hottest day ever, the lessons learnt were all formulated into an Operational Strategy document. Other good practices were added to this procedures manual. They included requirement of periodic commissioning and fine tuning and made it mandatory for all members of the facility management team to be more proficient with use of Building Management System (BMS). They have thereby incorporated some of the BMS functions such as Night Purge, Optimum Stop / Start, together with using the BMS as a diagnostic tool to address complaints regarding comfort. **Using the BMS to monitor the energy and water consumption, the Facility Managers are predicting an energy reduction of around 15 - 20% on an annual basis, with the adoption of this Operational Strategy.**

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Session

Efficiency in DC

NABERS for Data Centres: Development of Efficiency Ratings for Data Centres in Australia

Dr Paul Bannister, Haibo Chen, Chris Bloomfield and Caroline Residovic

Exergy Australia and New Zealand

Abstract

In recent years, data centres have become increasingly intensive users of electricity and emissions sources. In a bid to encourage efficient data centre practices, the Office of Environment and Heritage NSW (OEH), in collaboration with the Federal Australian Government Department of Climate Change and Energy Efficiency (DCCEE) commissioned a new performance based rating tool for greenhouse gas emissions from Australian data centres. The rating tool is designed to be part of the National Australian Built Environment Rating System (NABERS) family of ratings, and as such shares a common framework with other more established rating tools such as NABERS for Offices. The ratings assess greenhouse gas emissions on a 1 to 6 star rating scale, with 3 stars representing the median performance in the market, and 6 stars representing aspirational performance.

There are three rating types applicable to data centres based largely on the boundaries of control. These are: IT Equipment, Infrastructure and Whole Facility ratings. This paper will provide an overview of:

- NABERS as a performance based energy efficiency rating tool
- Statistical findings and benchmark models underlying NABERS Energy for Data Centres
- Benefits of the NABERS Energy for Data Centres benchmark model

Introduction – NABERS (National Australian Built Environment Rating System)

It is important to review how a performance based benchmark such as NABERS operates. There are essentially two types of efficiency rating tools available, design based and performance based. In design based tools, facilities are rewarded for features or designs that are thought to be efficient. On the other hand, performance based tools focus on comparing metrics such as measured energy consumption and productive output; facilities are deemed more efficient if they consume less energy for a given level of productive output. NABERS is a purely performance based rating tool that benchmarks emissions arising from energy consumption against population median levels to assess the facility's relative environmental impact when compared to its peers.

The following diagram provides a graphic depiction of how NABERS views typical data centre operations:

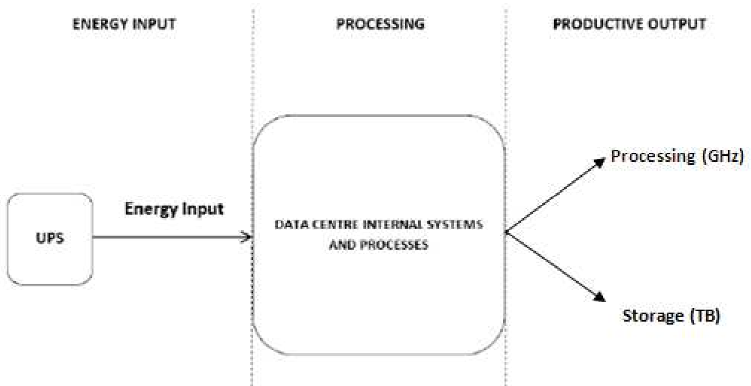

Figure 1: NABERS simplified treatment of data centre input/output (C.Bloomfield & H.Chen, 2012)

For illustrative purposes, consider a data centre replacing their existing RAID (Redundant Array of Independent Disks) with a MAID (Massive Array of Idle Disks) which is able to switch off idle disks until they are requested. Under NABERS, if the MAID works, productive storage output (total TB unformatted storage) is maintained while the energy input decreases (from switching off disks), resulting in a better rating. In essence, NABERS Energy for Data Centres is only interested in the achieved outcomes, and not in the method used to reach the outcome. In this manner, NABERS encourages innovation in the achievement of improved performance. This is in contrast to design-based systems, which inherently drive design decisions in a prescriptive manner, may hinder innovation and in some cases may even produce perverse outcomes.

Data Centre Rating Types

In line with the NABERS philosophy, NABERS Data Centres is split by boundaries of stakeholder control into three rating types:

- **IT Equipment rating**. This rating is suitable for tenancy data centres where the operators only have control over the IT equipment.
- **Infrastructure rating**. The Infrastructure rating assesses the efficiency of data centre infrastructure servicing IT equipment inclusive of power distribution, cooling and ventilation, security etc. This rating is suitable for colocation centres where the operators do not have control over any tenant IT equipment but provide cooling and power delivery systems.
- **Whole Facility rating**. This is a combined rating involving both IT Equipment and Infrastructure. This rating is suitable for whole data centres where the operators have full control over all aspects of data centre operations, including IT equipment and infrastructure, or where internal metering arrangements do not permit separate IT Equipment or Infrastructure ratings.

The classification of rating types (and the associated boundaries) is intentionally designated such that each rating type targets a particular group of industry stakeholders (e.g. data centre tenants, co-location providers and whole facility owner/operators) and that in turn, each group of stakeholders are held accountable for their performance/efficiency. In doing so, each rating type becomes a useful tool for direct measurement and comparison of efficiency performance; a data centre tenant cannot conceal poor performance as long as the infrastructure services are taken out of the equation. This approach ultimately drives change within the industry as market participants become increasingly competitive on the subject of efficiency; particularly as NABERS performance requirements become integrated with the procurement process (as has been achieved with the Offices rating tool).

Sample Data Overview

Data for NABERS Energy for Data Centres was gathered via voluntary questionnaires completed by data centre managers. Sufficient diversity was achieved in the sample data across demographic parameters such as size, location and ownership structure. Insufficient data was collected to facilitate meaningful analysis of energy consumption by industry sector.

A summary of the sample data demographics is provided below

Sample size by rating type		
Data Centre Type	**Sample Size**	**Total annual GWh Energy Use**
IT Equipment	26	47
Infrastructure	29	111
Whole Facility	17	103

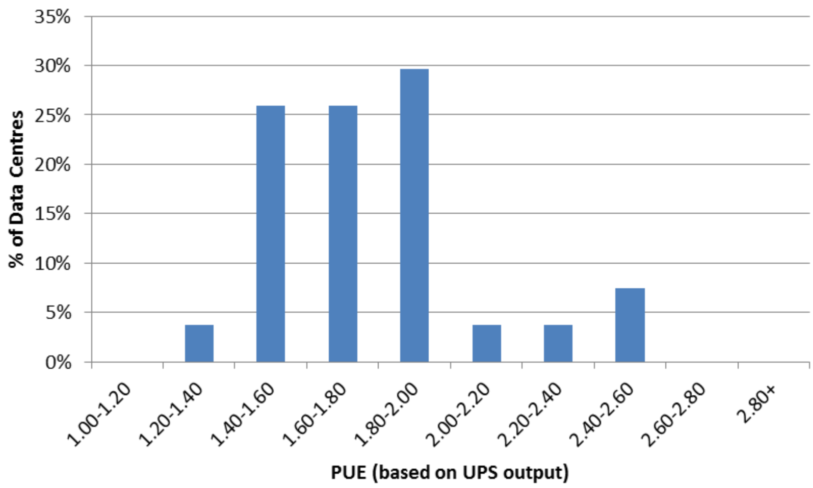

Figure 2: Infrastructure and whole facility sample PUE (Power Usage Effectiveness)

Notably in Figure 3, the distribution of data centre PUE is reasonably centralized about the 1.80 (median PUE) but the tail of the distribution is skewed towards the poorer end of the spectrum. This was to be expected as there is a practical limit to how efficient a modern data centre can perform but no real limit on how poor one may perform.

IT Equipment Benchmarking

Consumption Drivers

The purpose of the IT Equipment benchmark model was to relate data centre IT productive output to IT energy consumption. Unfortunately, the type of activities conducted in data centres vary significantly, and thus direct comparisons between sites are usually not meaningful without a way to interpret the differences. For example, direct comparison between an enterprise facility and an internet search facility would be near impossible since the quantity and type of equipment may differ substantially. While numerous existing computational benchmarks claim universal comparability, they have not been adopted under NABERS for a number of reasons. One such consideration was the unnecessarily prohibitive licensing and implementation overheads imposed on data centre owners in benchmarking all processing equipment (esp. in large facilities with thousands of servers).

Our approach was therefore to choose a set of proxies that closely relate to the primary data centre functions but which would be easily measurable and auditable. The challenge was to ensure that these metrics could reasonably represent all types of data centre output such that no particular facility type was unfairly penalised. The three fundamental types of data centre productive outputs regardless of its industry/function are: ***Processing***, ***Storage*** and ***Network Communications***.

Based on statistical analysis of the sample data conducted for the above productivity measures, the key drivers of IT equipment energy consumption identified were:

- ***Processing GHz***: Total Processing Output =∑ (GHz/core × number of cores)

Although crude, microprocessor clock speed in Gigahertz (10^9 Hertz) provides a means to assess the processing performance of each server irrespective of its make or model. The adoption of this metric presents several major benefits:

  - o Superior coverage of equipment – without the need for additional overhead associated with 3rd party benchmarks

- Availability of information – Note that processing utilisation was not incorporated as only a small portion of survey respondents were able to provide this level of information without significant resource expenditure.
- Industry familiarity – industry already familiar with method of measurement and limitations.
- Strong statistical correlation – significant correlation supporting its direct correlation to energy use.

- ***Unformatted Storage TB*:**

Total Unformatted Storage Capacity (TB) = Σ (unformatted TB available onsite storage)

In APC's White Paper #161 (Rasmussen 2009), storage related devices are estimated to consume up to 20% of the total IT equipment energy. This is a significant portion of the data centre energy footprint that NABERS must account for.

In selecting the most appropriate storage metric, several factors were considered

- Device types – In addition to hard disk drives and solid state drives, automated tape storage devices provide a similar function and should contribute to the total assessable storage capacity. Manual loading tape drives and external tape storage is not included in the total storage capacity.
- Utilisation – the amount of storage used is too difficult to verify as it can be easily manipulated. Complex redundant storage configurations also introduce significant challenges in the determination of utilisation.
- Formatting – To maintain consistency and to avoid introducing an unnecessary layer of complexity in the assessment of storage, NABERS assesses the total unformatted capacity of all storage devices. The use of unformatted capacity ensures that no particular file system or platform is disadvantaged
- On-site vs. Off-site – NABERS is a performance based benchmark tool that compares energy consumption for a given level of onsite productive output. For this reason, any offsite storage was excluded from benchmarking (and is excluded from NABERS ratings).

Data Centre Network Communications

There is a great deal of uncertainty surrounding the significance of energy consumed by networking and communications equipment. In the 2007 US EPA report to Congress, it was estimated that the energy consumption of network/communications equipment in the USA makes up approximately 10% of the total data centre IT energy consumption (US EPA, 2007). In its estimation, the US EPA assumed that any network equipment consumes on average 8W per physical port. However, in a more recent study carried out by the Lawrence Berkeley National Laboratory (Lanzisera et al, 2010), network consumption was found to vary between 1.4W to 3.6W per port depending on port throughput. This is an important finding as it suggests networking equipment may be responsible for a much smaller portion of energy consumption than initially thought. Adjusting the US EPA estimates accordingly, network equipment is expected to represent less than 5% of the total data centre IT energy consumption. This provides justification to exclude networking altogether from the energy benchmark.

The sample data set also supports the proposition that network communications is not a significant consumption driver. Analysis of the collected data reveals a strong cross correlation between GHz processing capacity and network ports. The correlation coefficient of 0.81 indicates a significant level of inter-dependency, i.e. the Total GHz processing metric adequately encapsulates the limited IT energy consumption arising from network communications.

Consideration was given to Power-over-Ethernet (PoE) equipment which has seen rapid growth in recent years. As a result of increased adoption, there is increasingly a shift in tenant energy consumption from the office space into the comms room/data centre. Devices such as phones and security systems using PoE can now draw up to 50W per port over the network in the latest generation of equipment, not to mention the significant transmission losses that are inherent to PoE due to the use of DC power. Based on the outcomes of industry consultation, the Technical Working Group agreed that where possible, PoE consumption would be excluded from the assessment of data centre efficiency.

Benchmarking Industry Median Performance of IT Equipment

The two most significant drivers of data centre IT energy consumption were processing capacity and storage capacity. To remove the effects of cross-correlation (inter-dependence) between processing GHz and storage TB, the sample data was first normalised by processing GHz, the largest consumption driver, prior to further regression analysis of the following relationship

The correlation between the normalised consumption and normalised storage capacity is demonstrated in Figure 3 below.

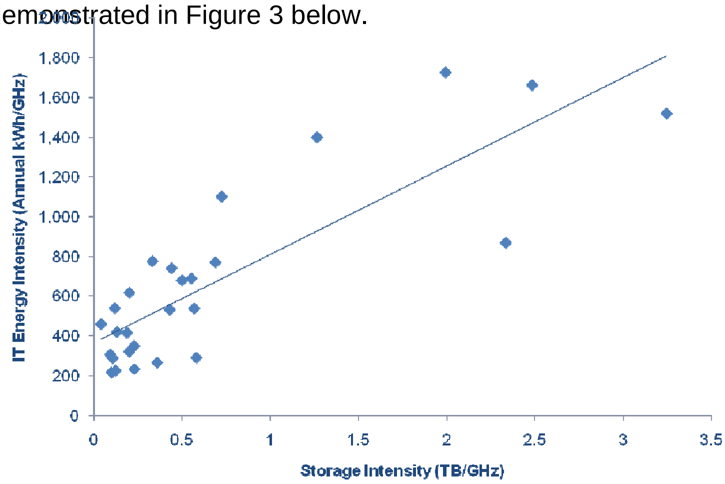

Figure 3: Strong correlation between storage intensity and IT energy intensity

The relationship was then quantified through linear regression which yielded statistically significant results with a regression coefficient R^2 of 0.69 (69% of variability in kWh/GHz normalised IT energy explained by TB/GHz storage intensity).

Perhaps most significantly, the resultant energy benchmark is able to explain over 93% of the total variability in IT Equipment energy consumption, this is illustrated graphically in Figure 4 below:

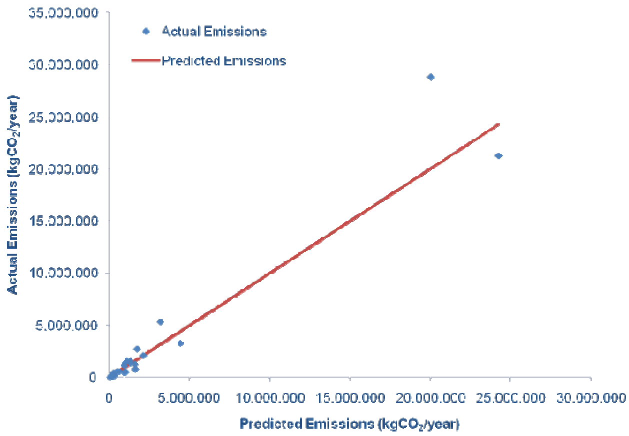

Figure 4: Actual emissions Vs. Benchmark predicted emissions

Subsequent residual analysis was also successful in demonstrating that there was no systematic bias within the regression models (no residual correlation against metrics such as size, capacity, consumption etc.…)

In keeping to a median GHG emissions benchmark, the linearised energy benchmark for IT Equipment was converted to an emissions benchmark through application of the National Greenhouse Accounts (NGA) factors (e.g. SGEe for electricity) and then corrected to a median benchmark via scaling against the sample median residual.

This performance benchmark model is used by NABERS to predict the industry median performance (annual GHG emissions) for the IT equipment in any given data centre, as long as processing and storage capacity information is available.

$$\%\ Deviation\ from\ Mean = \frac{E_{measured} - E_{median}}{E_{median}}$$

Where $E_{measured}$ is the total measured energy consumption and E_{median} is the total benchmark predicted energy consumption based on the processing and storage capacity metrics.

If a site consumes more energy than the benchmark model predicts (positive % deviation from median), then the site performs worse than industry median and is given a lower rating. In this way, the % deviation from the benchmark median will set the standards for the rating star bands. The distribution of sample data centres performance is presented graphically in Figure 5 below.

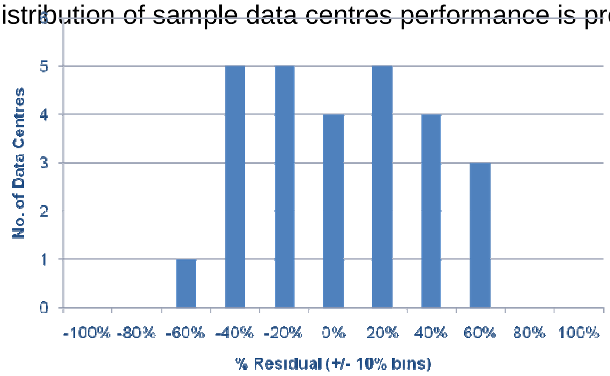

Figure 5: residual distribution of the IT Equipment Benchmark model

This residual (% deviation from benchmark median) distribution was transformed to a linear star rating system between 1 to 6 stars in 0.5 star increments to ensure a "desirable" distribution of rating outcomes. This was done in such a way that the final distribution has not many ratings either: below 1 star to make most of the data centre population rateable; or, above 5 stars to set the higher ratings (5.5 and 6 stars) as aspirational targets for new facilities or improvement works on existing data centres. "Average" performance (industry median emissions) was set to 3.0 stars.

IT Equipment Rating Emissions Thresholds

NABERS star rating (start of band)	% of benchmark median emissions	% deviation from benchmark median
6	15%	-85%
5	46%	-54%
4	77%	-23%
3	107%	7%
2	138%	38%
1	169%	69%

Infrastructure Benchmarking

Power Usage Effectiveness (PUE) and Emissions Index (EI)

The purpose of the Infrastructure energy benchmark model is to assess the energy efficiency of the data centre infrastructure in delivering support services to the IT equipment. Support services in this context refers to essential data services outside of IT operations, this includes mechanical services (HVAC), fire services, lighting (to data centres) and power back-up/distribution (e.g. UPS, PDU and diesel generators).

Unlike the IT Equipment rating, the Infrastructure rating ignores the composition of IT equipment and focuses only on the overall IT electrical efficiency or energy consumption. This approach ensures that colocation facilities providing only support infrastructure will not be penalised for inefficient IT equipment which are usually beyond their control.

Infrastructure energy consumption in data centres is driven entirely by the IT equipment loads that create heat rejection and power distribution requirements. Awareness of infrastructure energy efficiency has been rapidly improving in recent years with the now widespread use of the Power Usage Effectiveness (PUE) metric. Numerically, PUE is the ratio between the data centre's total energy consumption and its IT equipment energy consumption, i.e.:

$$PUE = \frac{Whole\ Data\ Centre\ Energy\ Consumption}{IT\ Equipment\ Energy\ Consumption}$$

To maintain international consistency, NABERS recognised PUE as a standard metric for data centre infrastructure energy efficiency and incorporated it into the rating system. However, as NABERS is an emissions based rating tool, it is necessary to express PUE in terms of fuel corrected emissions for rating purposes i.e.

$$Emissions\ Index = 1 + \frac{Infrastructure\ GHG\ Emissions}{IT\ Equipment\ \ GHG\ Emissions}$$

Where the GHG Emissions figures are obtained using the National Greenhouse Accounts (NGA) factors. As per many other NABERS tools, the data centre rating compares a data centre's measured infrastructure emissions with the industry median emissions benchmark to evaluate its efficiency performance. The figure below illustrates that there is an even and random distribution of sample data centres either above or below the median which is pivotal in maintaining an unbiased Infrastructure rating distribution.

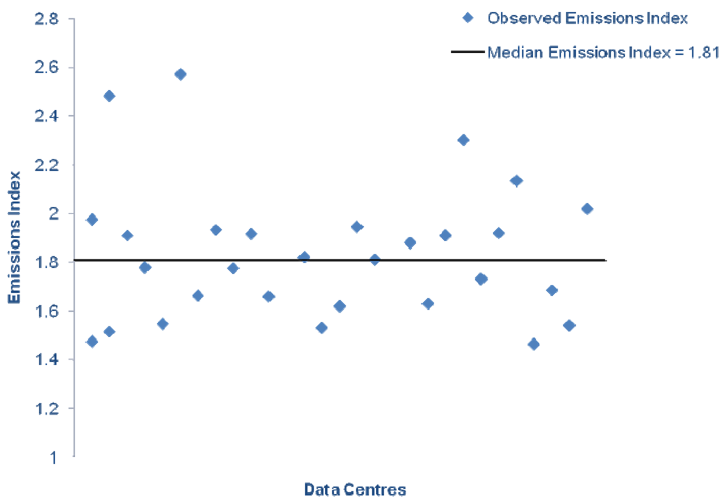

Figure 6: Distribution of sample data centre EI about sample median EI

The industry infrastructure emissions benchmark ($\boldsymbol{E_{median}}$) for a data centre is determined by its measured IT emissions ($\boldsymbol{E_{IT}}$ $kgCO_2$/year) and the industry median Emissions Index ($\boldsymbol{EI_{median}}$) which is based on the sample median EI (as a best estimator for population median EI).

Note that intentionally, the IT Energy and emissions associated with an infrastructure rating must be measured from the PDU output in line with The Green Grid PUE Category 2 classification (The Green Grid, 2010); this requirement arises from the industry recognised control boundaries (tenant vs. co-location) and guarantees consistency and comparability in the NABERS rating outcomes.

While the above describes the median benchmark for data centre infrastructure emissions, it does not account for variations arising from external factors such as climate and shared services (i.e. with other buildings/spaces). The following sections will examine the treatment of these external factors under the NABERS benchmark model.

Shared Condenser Water

Some data centres make use of a base building (or adjacent) building's condenser water loop for cooling plant heat rejection. This is usually a small proportion of the total data centre energy consumption (1-2%) but should regardless be taken into account for comparability and fairness, as the original median benchmark assumes a data centre provides its own heat rejection. A concern raised during industry consultation was that these data centres with "free" condenser water supplies may unfairly rate better than their dedicated/standalone counterparts.

To address this concern, a calculated correction has been developed that adjusts the median by an estimated energy "saving" associated with the lack of heat rejection energy consumption. The details of the derivation are available in the full report **(H. Chen et al, 2012)**, but in summary, the expected consumption associated with condenser water heat rejection is 0.04kW electrical per 1 kW of thermal heat rejected from the data centre (total thermal heat rejection requirement is well approximated by the whole facility energy consumption). The figures are based on the assumption of a water cooled system operating at average efficiency.

Notably, the calculation of "free" condenser water energy gained through shared heat rejection services takes into account the % of unmetered heat rejection shared with other non-data centre services. In this way, facilities being rated would not be excessively penalised if at least some of the heat rejection equipment has been metered and included in the overall rated energy consumption.

Climate Correction

The impact of climate on energy consumption (and consequently GHG emissions) has been a topic of contention throughout the development of the rating tool. To investigate the empirical impact of climate on energy efficiency, the metric for the cooling load of any climate zone, Cooling Degree Days (CDD) was compared to data centre infrastructure efficiency (PUE). Subsequent analysis did not uncover any statistically significant relationship between the two factors; notably, this empirical observation was similar to the conclusion drawn by the US EPA in their study of climate impacts on data centre infrastructure efficiency (US EPA 2009). Due to the lack of empirical evidence, the US EPA concluded that climate should not be corrected for in the US Energy Star rating tool for data centres.

However, response from the Australian data centre industry was to the contrary. Most members of the technical working group felt strongly that a climate correction should be incorporated into NABERS for one or more of the following reasons:

- In practice, there is definitely a small but observable relationship between infrastructure energy consumption and climate on a site-by-site basis. Figure 7 below illustrates the tures.

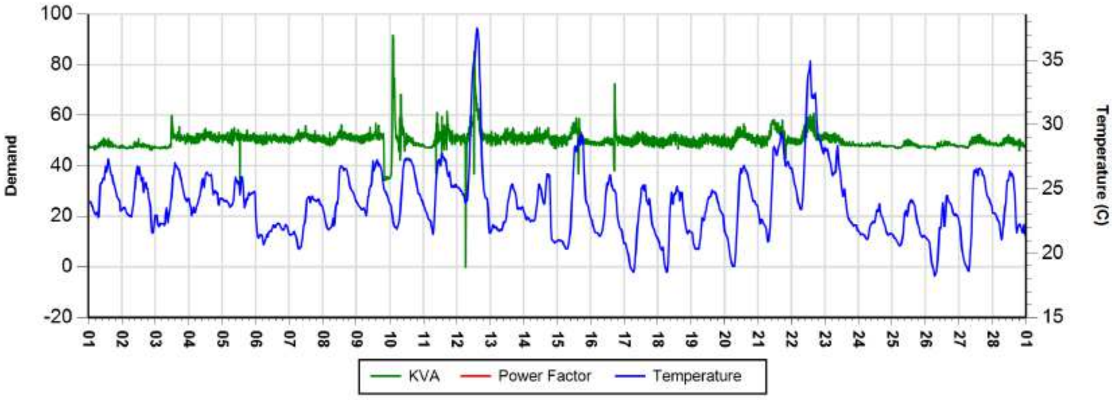

Figure 7: Outside air temperatures vs. data centre kVA demand (courtesy of Interactive)

- Some climate impact on PUE was observed for the US EPA data set when only looking at the subset of data centres not running an economy cycle.

- Not allowing for a climate correction if a significant climate effect exists could have a perverse effect on the geographic distribution of the data centre market; this is especially a problem when State and Territories are keen to keep data centres within their own jurisdiction.

Given these justifications, NABERS Energy for Data Centres incorporated a climate correction based on theoretical performances of data centre air conditioning systems. This was based on the following assumptions:

- The whole facility energy in kWh (IT energy + Infrastructure energy) is a good approximation for the total thermal heat rejected by the air conditioning system. This will take into account all heat losses from IT equipment, UPS/PDU losses, plant equipment etc.

- The average CRAC unit or chiller has a Coefficient of Performance (CoP) of 3.0

- The average climate impact on CRAC/chiller consumption is a 2% increase in energy consumption per 1°C of outside air temperature increase (wet bulb for water cooled chillers/units and dry bulb for air cooled chillers/units)

- A site's climate correction will be based on the deviation of its annual CDD from the NABERS sample average. This difference was then be converted back into °C

The derived climate correction is then applied to the benchmark median infrastructure emissions such that data centres located in hotter climates (higher annual CDD) are compared to a slightly relaxed benchmark/median that is allocated additional emissions to make up for lower heat rejection efficiency.

Final Infrastructure Benchmark

Allowing for the climate and condenser water corrections, the predicted median emissions for Infrastructure is calculated as follows:

$$E_{median} = Median\ Infrastructure\ Emissions + Climate\ Correction - CW\ Correction$$

This performance benchmark model is subsequently used by NABERS to predict the industry median performance (annual GHG emissions) for the infrastructure services of any given data centre, as long as the total IT energy consumption and climate of the site is known. The facility's measured consumption is then compared to the benchmark predictions in the following manner:

$$\%\ Deviation\ from\ Mean = \frac{E_{measured} - E_{median}}{E_{median}}$$

Where if a site consumes (***E**measured*) more energy than the benchmark model (***E**median*) predicts, then the site performs worse than industry median (positive % deviation) and is given a lower rating. In this way, the % deviation from the benchmark median will set the standards for the rating star bands. The distribution of sample data centres relative to the predicted median is presented graphically in Figure 8 below.

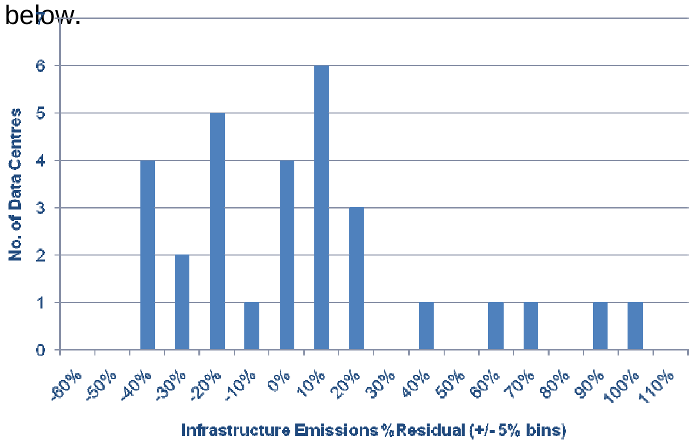

Figure 8: residual distribution of the IT Equipment Benchmark model

This residual distribution was then transformed to a linear star rating system between 1 to 6 stars in 0.5 star increments to ensure a "desirable" distribution of rating outcomes. This was done in such a way that the final distribution has not many ratings either: below 1 star to make most of the data centre population rateable; or, above 5 stars to set the higher ratings (5.5 and 6 stars) as aspirational targets for new facilities or improvement works on existing data centres. "Average" performance (industry median emissions) was set to 3.0 stars.

Infrastructure Rating Emissions and EI Thresholds			
NABERS star rating, at start of rating band	% of Benchmark median emissions	% Deviation from Median	Emissions Index cut-off (assuming no climate correction)
6	8%	-92%	1.07
5	42%	-58%	1.36
4	75%	-25%	1.65
3	108%	8%	1.94
2	141%	41%	2.22
1	174%	74%	2.51

Whole Facility Benchmark

Combined IT and Infrastructure benchmark

The whole facility rating is for data centres where both the IT equipment and infrastructure services are under the same ownership/control. It is also applicable to facilities where the separation between IT equipment and infrastructure is inadequate for other rating types.

The industry median whole facility emissions can be built using the two constituent benchmarks for IT Equipment and Infrastructure. Namely, the industry median emissions for IT equipment (**E_{IT}**) can be evaluated using the IT Equipment benchmark and this is in turn used to estimate the industry median infrastructure emissions (E_{Infra}) as per the below formula:

$$E_{median} = Whole\ Data\ Centre\ Emissions + Climate\ Correction - CW\ Correction$$

This performance benchmark model is used by NABERS to predict the industry median performance (annual GHG emissions) for the whole data centres, as long as the total GHz processing capacity, TB unformatted storage capacity and climate of the site are known. The % deviation from the benchmark median is again used to represent the efficiency of the rated facility relative to the market. If a site consumes more energy than the benchmark model predicts (positive % residual), then the site performs worse than industry median and is given a lower rating. In this way, the % deviation from the benchmark median will set the standards for the rating star bands. The distribution of sample data centres relative to the predicted median is presented graphically in Figure 9 below.

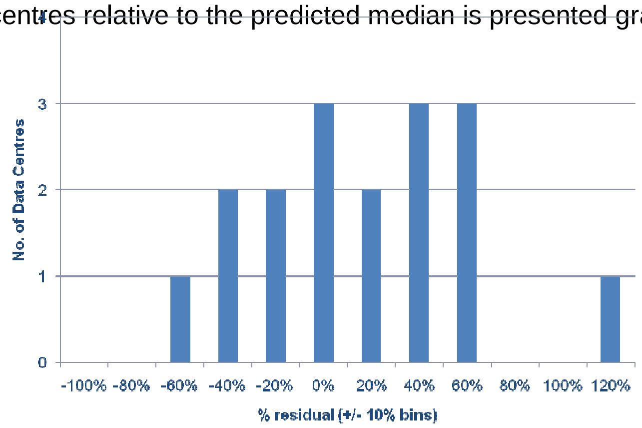

Figure 9: Distribution of Whole Facility benchmark model residuals

This residual distribution was transformed to a linear star rating system between 1 to 6 stars in 0.5 star increments to ensure a "desirable" distribution of rating outcomes. This was done in such a way that the final distribution has not many ratings either: below 1 star to make most of the data centre population rateable; or, above 5 stars to set the higher ratings (5.5 and 6 stars) as aspirational targets for new facilities or improvement works on existing data centres. “Average” performance (industry median emissions) was set to 3.0 stars.

Table 1: Star bands relative to the regression (average) equation

NABERS star rating, at star of band	Emissions compared to benchmark median	% Deviation from benchmark median
6	20%	-80%
5	49%	-51%
4	78%	-22%
3	107%	7%
2	136%	36%
1	165%	65%

Benefits of NABERS Energy for Data Centres

First rating tool with dedicated IT Equipment rating - NABERS Energy for Data Centres was first released in 2013 and is the first data centre efficiency rating to separately assess IT Equipment efficiency on a large scale. While much attention and resources have been invested towards the reduction of data centre PUE, the efficiency of IT equipment have been largely vendor driven in part due to a lack of auditable metric for IT equipment efficiency. NABERS provides this metric and a starting point for the market transformation towards more efficient data centre tenant equipment.

Rating types based on ownership/control – The classification of rating types according to the associated ownership/control boundaries ensure that ratings are targeted at the most relevant stakeholders. The unambiguous distinction of the rating boundaries ensures that stakeholders are held accountable for the aspects of data centre performance/efficiency that they have direct control over.

Rating coverage – the rating inputs required under NABERS are well known and have been selected with consideration to broader availability. It is the intent of NABERS that the rating tool is able to reach as much of the industry as possible by minimising the overheads associated with obtaining ratings.

Consistent measurement methodology – NABERS provides a consistent assessment methodology that has developed in parallel with ongoing industry consultation. A single prescribed methodology for performance assessments will assist in producing unbiased ratings that will hopefully become a point of product/service differentiation within the market, driving efficiency improvement along the way.

Comparability – the use of a statistically sound benchmark models ensures that a customised benchmark is matched against each individual data centre undertaking a rating, enabling direct comparison for sites against industry median irrespective of size, functionality and location.

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[4] US Environment Protection Agency, *Report to Congress on Server and Data Centre Energy Efficiency Public Law 109-431.* Prepared for US Congress as part of the ENERGY STAR Program, 2007

[5] US Environment Protection Agency, *Energy Star Data Centre Infrastructure Rating Development Update*. US EPA web conference, 29th September 2009

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ENERGY STAR® Developments in the Data Center

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Abstract

Recent developments in computer server and data center storage products have led to tangible increases in energy efficiency in data centers at the product level. Working with a variety of stakeholders from private industry to foreign governments, the U.S. Environmental Protection Agency (EPA) has recently completed new ENERGY STAR specifications in both product categories. These new specifications utilize test tools developed with industry partners, the results of which are published online and will be used to develop future idle and active mode energy performance criteria.

The development of these specifications has led to several unique challenges, including accounting for fast paced technology improvements, new and complex testing tools, and quickly shifting trends in both the computer server and storage markets. This paper will describe these challenges and how they were overcome, with the goal of providing insight for other parties interested in data center product energy efficiency.

EPA has observed many new developments related to computer servers and data center storage through recent work with industry and other interested parties. This paper will describe upcoming trends and how they may aid in reducing energy consumption of enterprise information and communication technology (ICT) hardware.

On a building scale, this paper will present a summary of recent case studies highlighting ENERGY STAR Low Carbon IT Champions. These are companies who have significantly reduced operational costs in their data centers with the aid of the ENERGY STAR Portfolio Manager tool.

Introduction

Energy saving opportunities in data centers are well documented, but barriers to implementing the necessary solutions still exist. Of particular note are information barriers—how much energy and money will a given change save, or what are the more efficient products that will save more in the long run? Knowing that a solution exists does little to clarify its efficacy. More precise data is needed. Through ENERGY STAR, EPA is addressing these information barriers in a two pronged approach.

To address IT product efficiency, EPA develops ENERGY STAR product specifications and publishes test results online. This helps purchasers more easily identify energy efficient IT equipment including computer servers, uninterruptible power supplies, data center storage and large network equipment. This differentiation helps data center owners and operators select products that will save them money on their energy bills, assists manufacturers of efficient equipment in increasing sales, and drives down or reduces the rate of increase of data center energy consumption—estimated to be more than 2% of total annual U.S. electricity consumption [1].

To address overall data center efficiency above the product level, EPA has incorporated data center elements into the ENERGY STAR Low Carbon IT Campaign. These data center specific efforts include:

- Expanding the ENERGY STAR Portfolio Manager tool (used for measuring commercial building efficiency) to apply to data center infrastructure, including standalone data center buildings, as well as those enclosed within larger structures. Through a scoring system, data center managers can assess the energy efficiency performance of their data center, helping users identify cost effective methods to increase their score and track the effects of their improvements. Those who place in the 75th or higher percentile in a given year, when compared to similar “peer” data centers, achieve ENERGY STAR recognition for their facility. The program and tools are open to any interested parties [2].

- Providing data center best practices through the Top 12 program, which identifies the top twelve recommended ways to reduce energy consumption in data centers and provides case studies of organizations that successfully improved their facility’s energy efficiency [3].

The following sections will provide detail on how recent IT product specification development and expansion of the Portfolio Manager tool have helped lead to decreased energy usage in data centers.

Overview of ENERGY STAR Product Specification Development Process

Products can earn the ENERGY STAR label by meeting the energy efficiency requirements set forth in ENERGY STAR product specifications. EPA establishes these specifications based on the following set of key guiding principles:

1. Product categories must contribute significant energy savings nationwide.
2. Labeled products must deliver the features and performance demanded by consumers, in addition to increased energy efficiency.
3. If the labeled product costs more than a conventional, less-efficient counterpart, purchasers will recover their investment in increased energy efficiency through utility bill savings, within a reasonable period of time.
4. Energy efficiency can be achieved through broadly available, non-proprietary technologies offered by more than one manufacturer.
5. Product energy consumption and performance can be measured and verified with testing.
6. Labeling would effectively differentiate products and be visible for purchasers.

Figure 1 below summarizes the individual steps that are taken in the creation of a new ENERGY STAR product specification. High market penetration of labeled products, changes to federal standards, and significant technological developments are common triggers for starting revisions of existing product specifications.

Figure 1: Typical ENERGY STAR Product Specification Development Cycle

Challenges Incurred During Recently Completed Specification Development

In 2013, EPA finalized a revision to the existing ENERGY STAR Computer Servers product specification (Version 2.0) and a brand new ENERGY STAR product specification for Data Center Storage (Version 1.0). Several factors influenced the development of the completed specifications, including the incorporation of new industry test methodologies for active energy efficiency and accounting for significant technological developments which altered the performance or power of products during the period of specification development.

The subsections below describe particular issues encountered in each product category, and how EPA addressed them in ways that led to more effective energy efficiency programs for the products covered. Additional information on product specification development can be found on the ENERGY STAR website[1].

Computer Servers

Development of the ENERGY STAR Version 2.0 Computer Servers specification revision began in September 2009 and was completed in March 2013. This period coincided with the development of a new industry active energy efficiency test tool produced by the Standard Performance Evaluation Corporation (SPEC), called the Server Efficiency Rating Tool (SERT™)[2].

The ENERGY STAR team, consisting of EPA and U.S. Department of Energy (DOE) members, engaged with SPEC throughout the SERT development process with weekly check-in calls, and participated in validation testing of beta versions of the tool. EPA and SPEC wished to cover as many product types as possible with the SERT tool, but limited resources did not allow for inclusion of DC servers or ARM based architecture at the finalization of SERT v1.0. Since that time, 32-bit ARM architecture has been added to the testing suite, allowing a larger portion of microserver products to become ENERGY STAR certified as they can now provide the required SERT test data.

Beyond the mechanics of the tool development, there were reservations among some stakeholders about making SERT data available to the public—a key requirement for certification. Concerns were raised that since SERT was brand new, there was no guarantee that the results generated would fairly represent all product categories tested. EPA and stakeholders worked together to develop a compromise where all SERT data would be collected at the time of certification, but it would not be made public until the ENERGY STAR team and stakeholders could verify that the results were reasonable for the covered product categories. A meeting to discuss these findings is planned to occur in late spring 2014 and, barring any significant setbacks, EPA intends to publish all SERT results after this time.

Along with the addition of SERT, EPA extended the scope of the Version 2.0 program to include blade and multi-node servers. Since data is scarce and testing is costly, idle efficiency requirements were not created for these new products, but idle and active energy efficiency data is being collected on all certified products with the intent to set requirements in Version 3.0. Blade servers posed a particular problem in testing, as there was strong stakeholder disagreement over whether testing should focus on fully populated chassis or half populated chassis. From the limited data available, the ENERGY STAR team determined that fully populated chassis testing produces more accurate per-blade power and performance results. However, there is no standard size for a full chassis. The largest chassis for one manufacturer may hold twelve blades, while another may be able to fit nearly three times that number. It is important that all blade chassis are tested in a consistent way, both for fairness and to generate useful data for public consumption and future level setting in Version 3.0. As a compromise, EPA and DOE determined that all blade servers would be tested with half populated chassis, but manufacturers would have the option to submit full chassis data to display improved results if desired. This was a tradeoff that likely resulted in a slight decrease in accuracy but gained a great deal more data for public use.

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[1] www.energystar.gov/productdevelopment

[2] http://www.spec.org/sert/

Another addition to Version 2.0 was the creation of the resilient server category and the development of idle efficiency requirements specifically tailored to it. These computer servers provide higher operational redundancy for use in more extreme environments or sensitive applications, but consume more energy as a result. EPA received requests from stakeholders to include this new category, but had very little data on it. Manufacturers provided the needed input to create a definition of a resilient server and the data to set a separate resilient server idle requirement, as well as the addition of a new buffed DDR channel memory adder to compensate for higher functionality in the memory supporting hardware installed in these products. EPA performed its own analysis and market research to confirm the supplied information and ultimately decided to include these products.

Version 2.0 includes a new product family structure that represents a significant change from the existing Version 1.0 structure. For model lines that contain configurations with highly differing or variable internal hardware, ENERGY STAR allows for representative products to be tested and used to define a wider family of similar products. The Version 1.0 specification implemented a family structure with requirements that resulted in very complicated and burdensome testing of potentially dozens of configurations to cover all related computer servers a manufacturer wanted to certify within a given model line. The new approach in Version 2.0, shown in Figure 2 below, reduces the required testing down to five points which represent the minimum and maximum configuration bounds of a product family marketed as ENERGY STAR, as well as a representative typical configuration used as the basis for publically displayed product data—four corners and a point somewhere in between. Any configurations in the family whose hardware falls inside the four corners of the family can be marketed as ENERGY STAR.

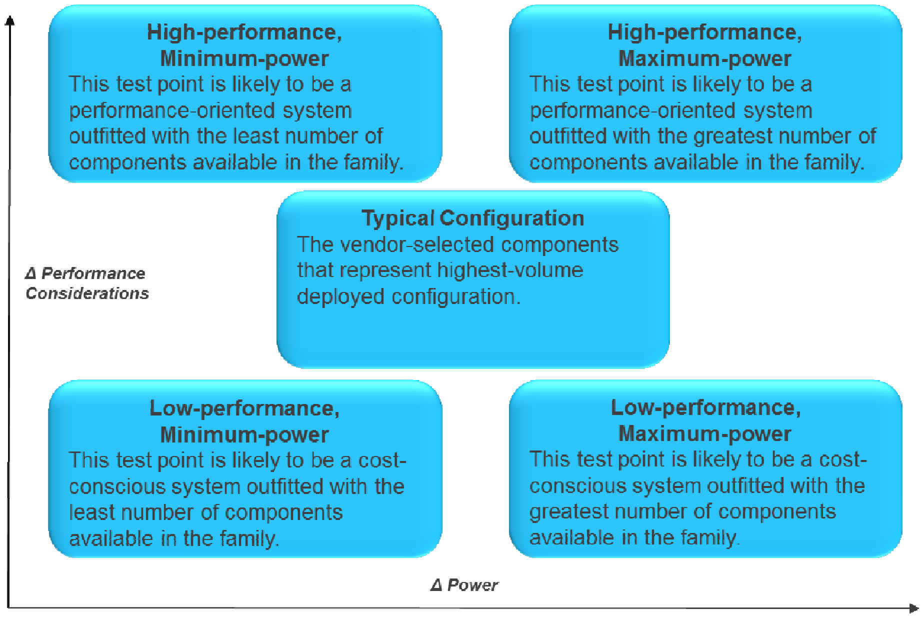

Figure 2: Five Point Computer Server Version 2.0 Family Structure

New data from multiple memory manufacturers showed that the memory adder in the one and two socket idle efficiency requirements was too lenient in newer systems. Lower voltage memory was allowing for significant decreases in energy consumption [4]. To determine the new adder, EPA took a subset of products from the Version 2.0 dataset which shared all attributes other than hard drive count and amount of memory. The hard drive idle power was subtracted out using specification sheets for each hard drive, resulting in pure GB/W memory idle values for roughly a dozen systems in the dataset. The data ranged from 0.6-1.0 watts/GB, and with this EPA and stakeholders agreed on a new level of 0.75 watts/GB, down from 2.0 watts/GB in Version 1.0.

The final challenge unique to computer servers was addressing the presence of auxiliary processing accelerators (APAs), commonly referred to as GPGPUs though named APAs in recognition that not all such products are now GPU based solutions. Manufacturers provided several examples of computer server products which contained APAs for specific computing purposes, providing a moderate level of high performance computing ability within otherwise traditional computer servers.

Since this hardware is in demand for certain computationally intensive end-uses, EPA recognized the need to include it. However, we needed to ensure that APA energy consumption was captured in testing and that there was an upper limit on the power APAs could consume in idle. As a result, computer servers sold with APAs are required to provide test data both with and without APAs installed. Additionally, to limit overall energy consumption, EPA required that each individual APA installed in an ENERGY STAR computer server shall not exceed 46 watts in idle, a value agreed upon based on recent GPU test data.

Data Center Storage

Development of the ENERGY STAR Version 1.0 Data Center Storage specification began in April 2009 and was completed in August 2013. Similar to computer servers, the development of the data center storage specification coincided with the development of a new industry energy efficiency test benchmark produced by the Storage Networking Industry Alliance (SNIA), called the SNIA Emerald™ Power Efficiency Measurement Specification[3]. EPA chose to focus the scope of Version 1.0 to Online block I/O systems, those with response times less than 80 milliseconds and which could be tested using the Emerald specification. EPA and stakeholders agreed that this segment of products made up a significant percentage of storage products sold within the scope of the Emerald specification. Other data storage types either do not have test procedures or have very little room to differentiate between the efficiency of different products (e.g. tape storage).

In the beginning of development, EPA intended to set idle efficiency levels to model the approach taken in the computer server specification. Unfortunately, storage testing requires significant time and cost and manufacturers could not afford to perform much testing that would not also have been usable for certification—so testing to support the development of a specification that was still under development was understandably a risky proposition. In addition, EPA and stakeholders came to the conclusion that active mode efficiency levels would have to be set in Version 2.0 based on data submitted in Version 1.0. But this long term goal created a problem with setting idle levels in the short term (Version 1.0). To maximize idle efficiency in a storage product, a manufacturer typically fills a system to maximum capacity to reduce the power component of the controller during a GB/watt measurement. By contrast, active mode efficiency requires that the product is loaded with the appropriate number of drives to maximize the performance of the controller without overburdening it and usually suffers from maximizing system capacity. Setting idle levels would result in systems optimized for idle, skewing active mode efficiency results away from their peak and creating useless or inaccurate active peak efficiency information.

Despite the cost burden of testing reduced the data available for analysis, over time SNIA was able to share small amounts of data which came from validation testing during the development of the Emerald specification. That data was instrumental in defining three representative workload types, addressing differences in scale-up vs. scale-out architecture, and refining product certification ranges and product family requirements.

Based on the workloads tested within the Emerald specification, EPA chose to define three representative workload types for storage product configurations; transaction, streaming, and capacity. The transaction workload focuses on Input/Output Operations Per Second per Watt (IOPS/watt) measurements of storage products, where random reads and writes dominate the workload. The streaming workload focuses on Megabits Per Second per Watt (MBPS/watt) measurements, where sequential reads and writes dominate the workload. Finally the capacity workload represents Online systems which act more like archival systems where maximizing GB/watt is most meaningful, though they still require a response time of less than 80 milliseconds. Storage product configurations are optimized for one of these workloads during testing, though manufacturers can combine test results from multiple configuration types to create a product family.

In addition to the workload types, EPA had to differentiate between scale-up and scale-out storage architecture. Scale-up products are comprised of one or more controllers which can control all storage devices within the product, while in scale-out products controllers only have a partial view of all the storage devices in the overall product. Scale-up architecture allows for end-users to add capacity to

[3] http://snia.org/emerald

an existing product at a drawer or even device level, while scale-out architecture typically expands by discrete nodes or large static blocks of hardware. The certification range and product family requirements in Version 1.0 were designed primarily with scale-up architecture in mind, but were also applied to scale-out with a few additional caveats.

Because EPA was no longer setting idle efficiency requirements, it placed requirements on power supply efficiency and restricted the size range of each product (device count) such that only the more efficient sizes could earn the label. This range was originally proposed to be symmetrically centered on the optimal performance/watt point in system size, and configurations with system sizes outside the range would not qualify. Due to the nature of scale-up architecture, where systems are often sold below the optimal system size and then built up over time, this certification range was ultimately shifted downward in system size to allow end-users to expand their product up to the optimal efficiency point. Additionally, several sources of data showed a significant drop off in performance/watt past this optimal point, so it was prudent to more severely restrict qualification on the upper end of system size. An example of the default and potential expanded certification ranges for storage products is shown in Figure 3 below.

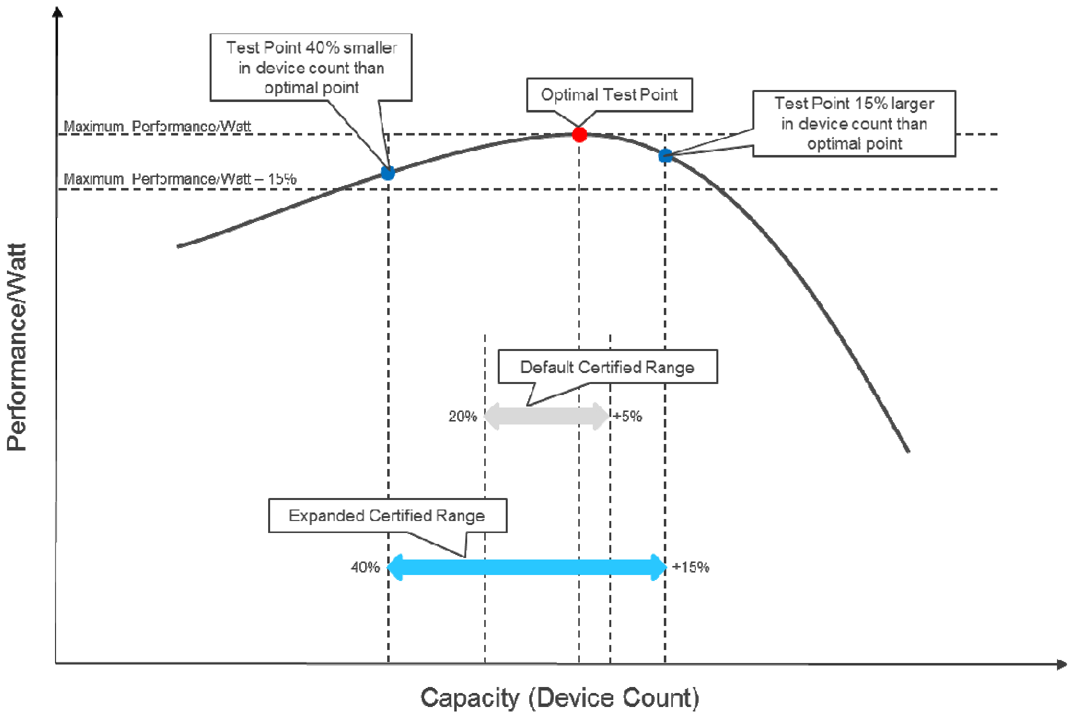

Figure 3: Example of Certification Range Scenarios Using Default Testing Range

Another area which required significant changes was requirements for capacity optimization methods (COMs), tools developed to ultimately reduce the number of storage devices required to store a given amount of data. Examples of COMs include compression, delta snapshots, deduplication, and thin-provisioning. EPA originally proposed to require all of the above COMs on larger Online systems, and at least two on the smaller systems. Further discussions with manufacturers revealed that some COMs are only beneficial for certain workloads and can actually decrease performance/watt results when enabled in other workloads because they provide no tangible benefits but require additional overhead. Additionally, manufacturers provided examples of older storage products still sold on the market which did not have any available COMs, but were competitive in performance/watt results. As a result of these discussions, EPA lowered the number of COMs required for all Online products, with only the largest Online 4 category having a requirement of at least one available COM in Version 1.0.

A final late challenge was adding guidance for storage products with automated storage tiering technology. Automated storage tiering involves intelligent movement of data between different drive types within a storage product. Early versions of the Emerald V1.0 specification were not designed to handle systems which had this capability, typically made up of a combination of slower spinning disk drives for streaming workloads and faster solid state drives for transaction workloads. The final version of the Emerald V1.0 specification included new provisions for testing storage products with automated storage tiering capability. EPA revised the approach on how to create certified product families to include “auto-tiered” solutions, allowing manufacturers to limit testing for certain products which offered static device configurations with automated storage tiering enabled.

Upcoming Technology Trends Identified During Specification Development

During the development of the most recent computer server and data center storage specifications, several technologies and trends emerged as areas to monitor moving forward when considering product energy efficiency. The subsections below highlight some of these trends and areas where EPA hopes to see continued innovation.

Computer Servers

Increased adoption of server virtualization over the past few years has been expected to lead to increases in computer server utilization rates. Unfortunately, in many data centers utilization rates have only grown to 10-20% [5], from a typical utilization of 5% in 2009 [6]. EPA has learned anecdotally from stakeholders that resilient server utilization rates are growing closer to 50%, and certain companies have created purpose built servers for specific workloads that achieve upwards of 80% utilization. A new, comprehensive survey to update utilization rates would be quite useful to evaluate these claims. EPA feels it is important to continue to monitor the effects of new technology on utilization rates, as improvements in utilization can outweigh improvements in overall data center PUE and power supply efficiency when determining energy savings potential [5]. As servers become more effectively utilized, the focus on active efficiency requirements in the upcoming Version 3.0 specification becomes even more important, as the servers spend more time performing work.

Another technology that EPA sees growing in popularity are microservers. These servers can be powered by low end traditional server processors or processors typically found in mobile devices, and can provide high density computing at power levels in the single watt range per processor [7]. Combining the energy efficient qualities of a blade server (e.g. shared power supplies, cooling fans, and chassis) with many low power processors, microservers appear to be a promising development in efficient computation for simpler tasks such as web hosting. As mentioned above, most microservers can now be tested using SERT and therefore are covered under the current Version 2.0 specification.

In product hardware, EPA is monitoring the growth of DC powered servers and servers that can meet ASHRAE A3 levels. End to end DC power in data centers has been shown to be more efficient than AC end to end power at low load levels (10-50%), comparable at medium load levels (50-80%) and slightly lower than AC at high load levels (80-100%) [8]. While DC input power may dramatically increase the efficiency of server products themselves by removing the AC-DC conversion loss within the product, the overall effect on data center energy efficiency is still unclear given this dependency on load levels. In regard to operating temperature, most existing server components can meet ASHRAE A2 levels[4] [9], but EPA has spoken with other governments and NGOs about desires to raise this level to A3 and beyond. There is a great opportunity for energy savings by shifting toward much wider environmental tolerances for data center products.

Data Center Storage

EPA is tracking a newer form of grid based scale-out architecture, in which discrete modules work together in a grid format to provide the appearance of a single storage space in the storage network. Applications have access to all modules within the product at any given time, with data being distributed evenly across all devices in the storage product [9]. One of the promises of this architecture is improved efficiency of automated storage tiering. Manufacturers have shared with EPA that current automated storage tiering software varies in effectiveness from product to product and vendor to vendor. Increasing the effectiveness of automated storage tiering can result in the system using less computational power to better place data on the most appropriate drive types based on

[4] http://www.eni.com/green-data-center/it_IT/static/pdf/ASHRAE_1.pdf

workloads present in a storage device with multiple drive types. The result is an increase in the performance/watt of the storage product.

Another significant type of storage that is not currently covered in Version 1.0 is storage products that implement network attached storage (NAS) only. Unified storage products which contain both block-based and file-based I/O within one product are covered in Version 1.0, but only their block I/O performance/watt are accounted for. The SNIA Emerald specification does not contain provisions for testing file-based I/O performance/watt, which results in NAS-only systems being excluded from ENERGY STAR. According to Gartner Research, NAS-only storage products made up 64.2% of the global revenue share of combined NAS and Unified storage in 2012 [10]. EPA looks forward to industry developing a new methodology to test file-based I/O performance/watt so that NAS-only storage products can be included and unified products can be tested in both operating modes.

Successful Case Studies from the ENERGY STAR Low Carbon IT Program

EPA has certified a total of 55 ENERGY STAR data centers between 2010 and 2013 through the use of the Portfolio Manager Tool. Inputs for this tool include variables related to size, IT energy configuration, annual IT energy consumption, along with at least twelve months of uninterrupted reporting of total building energy use. Data centers whose resulting ratings lie in the top quartile when compared to similar data center types become eligible for ENEGY STAR recognition. The three groups below have been highlighted as ENERGY STAR Low Carbon IT Champions specifically for their efforts in reducing energy consumption in their data centers with the aid of the Portfolio Manager Tool.

Common low cost improvements included installation of variable frequency drive (VFD) motors, improvements in air handling, and adjustments to ambient temperature and humidity settings in the data center. Additional information on these efforts beyond the summaries below can be found on the ENERGY STAR Low Carbon IT Website[5].

BNY Mellon’s Critical Systems Group

BNY Mellon, a leading investment management and investment services company, leveraged their existing Power Usage Effectiveness (PUE) program to help their Northern Pennsylvania Processing Center (NPPC) become the second data center to ever earn the ENERGY STAR buildings designation in 2010. Within their PUE program, infrastructure upgrades were only considered if they yielded a complete return on investment (ROI) within three years. The following energy efficiency upgrades were performed as a result of their PUE program:

- Installation of VFD motors on fan systems which led to a 25% average reduction in fan speeds.
- Fitting hot air collars at the server outlet that directed hot server air to a return air ceiling plenum. Additional air flow management measures such as blanking panels and grommets were also installed.
- Increasing supply air temperature to the servers from 22 to 26 degrees C. This allowed BNY Mellon to increase chilled water temperature from 6.5 to 8.5 degrees C, decreasing energy requirements to cool water.
- Changing humidification set points from 40% to 45% relative humidity to 5.5 to 15 degree C dew point, following newer ASHRAE guidance. This change led to a decrease in adiabatic humidification run-time from 80% to 20% of the time.

Water-side economizer improvements were investigated, but it was determined that capital costs for the equipment upgrades outweighed the potential energy savings, resulting in a payback of fourteen years which far exceeded the three year ROI target set by the group.

[5] http://www.energystar.gov/lowcarbonit

The results of these improvements include a change in PUE score from 2.0 in 2008 to 1.52 in 2012. In addition, 24 million kWh or $1.7 million dollars in electricity costs have been saved since the implementation of improvements as a result of BNY Mellon's PUE program.

RagingWire's Critical Facilities Team

RagingWire is a colocation facility in Sacramento, California that provides enterprise-class, high-power density data center space to many various companies. Colocation facilities can face greater efficiency challenges than purpose-built data centers because they support mission critical IT needs which require higher power density requirements to support the newest data center IT products available. RagingWire's PUE prior to improvements was already a fairly low 1.65 in 2008, however they proceeded to make the following improvements:

- Installation of a wireless data center floor environmental monitoring system (temperature and pressure), with multiple sensors installed in each rack. This monitoring ability allowed RagingWire to carefully increase the chilled water supply temperature from 10 to 15.5 degrees C while maintaining ASHRAE temperature and humidity guidelines.

- Improvements in hot aisle containment, including the installation of plastic curtains at the end of each hot aisle, installation of blanking panels inside racks to further isolate the cold and hot aisles, and installation of extended return air ducts on CRAH unit air intakes to prevent cold air from short-cycling back into the CRAH intake, resulting in higher CRAH unit efficiency.

- Implementation of a chiller plant quick restart program, which retuned the chilled water supply temperature to the established set point within two minutes following a power interruption. The accelerated startup enables to the plant to return to a steady-state, lower-energy consumption status more quickly than the original configuration.

- Installation VFD motors on all mechanical cooling pumps, chilled water pumps, and data floor CRAH units. This improvement led to a 42% average reduction in fan speeds. The installation of VFD motors also allowed for CRAH units to operate at higher speeds to compensate for a neighboring offline CRAH unit when needed, minimizing the need to start up a separate backup CRAH unit.

The improvements above led to annual savings of over 8.1 million kWh or $900,000 in electricity costs and a PUE decrease from 1.65 in 2008 to 1.48 in 2011. As a result, the RagingWire data center became the first colocation data center to earn the ENERGY STAR buildings designation in 2011.

Target's Technology Center Engineering Team

Target, a large U.S. retail company, operates two 45,000 square-foot data centers in Brooklyn Park and Elk River Minnesota which are a critical part of the company's business and infrastructure. In 2009, as part of an internal commitment to sustainability, Target identified and ultimately implemented the following improvements:

- Installation of VFD motors on all CRAH units, air handling units, and exhaust fans. Incorporation of VFDs allowed both exhaust fans and air handling units to be run at reduced fan speeds because they were previously redundant without VFDs. Fan speeds were reduced by as much as 78% in some circumstances.

- Reduction of temperatures on power generator heaters. Standby generator jack and oil warmers are typically used which use electricity to maintain the system in standby mode at all times. Working with the manufacturer of the generator, Target reduced the temperatures from 60 to 43 degrees C, resulting in a 4 kW decrease in the power consumption for each of the 16 heaters in use.

- Installation of timers and efficient lighting. Timers for lighting were set to turn on at 6:00am and turned off at 4:30pm. T-12 bulbs were replaced with T-8 bulbs, and high-beam metal halides were replaced with high-output T-8 bulbs.

- Powering down of unloaded transformers. Two unloaded 300 kVA power distribution units were taken offline, where computing load had not yet been built out to make use of them.

Target also investigated water-side economizers, and like the previous BNY Mellon example, they decided that the significant costs in retrofitting the chiller equipment were not justified given the payback period which they calculated to be 8.5 years in their case. Temperature and humidity adjustments were not made as part of their improvements, as they had already been adjusted in previous upgrades.

The improvements led to an annual savings of over 5.8 million kWh of electricity, with a 1.4 year payback period. The measures led to a 25% overall power savings on the mechanical loads in the two data centers. These savings resulted in Target being the first company to have two data centers earn the ENERGY STAR building designation.

Conclusion

Through the continued development of ENERGY STAR IT product specifications and the labeling of ENERGY STAR data center buildings, EPA remains committed to improving energy efficiency in data centers. EPA's current product specification work includes further development of the ENERGY STAR Version 1.0 Large Network Equipment product specification, and investigation of additional savings opportunities in data center cooling.

Developing efficiency requirements for such complicated technology has required a great deal of effort on the part of both the ENERGY STAR team and stakeholders. Collaborations with outside groups of experts have been crucial, as has a willingness to experiment with non-traditional approaches to setting requirements and defining product families. Tradeoffs have been made in the short term that will payoff in the form of increased participation, better data, and more stringent levels in the long term. Flexibility was needed to adapt to technology that changed rapidly during specification development. Finally, ENERGY STAR's data center work has demonstrated that cooperation between government, industry, non-profits, and other stakeholders can result in demonstrable benefits to all parties and the general public.

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Analysis and Results of the European Code of Conduct for Data Centres

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Abstract

The European Code of Conduct for Data Centres is a voluntary market transformation programme addressing primarily data centre owners and operators, and secondly the supply chain. The Data Centres Code of Conduct has been created in response to increasing energy consumption in data centres and the need to reduce the related environmental, economic and energy supply impacts. The aim is to inform and stimulate operators and owners to reduce energy consumption in a cost-effective manner without hampering the critical function of data centres. It also introduces a set of metrics to measure the energy efficiency. The data centre supply industry can join the programme by offering products and solution to help achieving the energy savings. Since the start of the programme in 2008, 220 Data Centres have been certified as Participant. The core of the programme is the commitment by the participant to carry out an initial energy audit to identify the major energy saving opportunities; to prepare an Action Plan; to implement the Action Plan; and to monitor energy consumption. The paper reports on the results achieved so far in terms of energy savings and technologies adopted, the participant motivations to join the programme and it suggests additional market transformation measures to improve data centres energy efficiency.

Introduction

Energy consumption in the commercial (service) sector has increased over the year, mainly due to the economic expansion of the sector, the increases in cooling loads, and the increased load of Information and Communication Technologies (ICT). In the commercial sector electricity consumption in the European Union (EU 28) has increased in the period 2003 to 2012 from 698 TWh to 845 TWh, i.e. a growth of 21%, while total electricity consumption in the EU 28 in the same period has grown by 4%, and in the residential sector by 5%. The JRC Energy Efficiency Status report 2012 has evaluated the data centres total energy consumption as 56 TWh or 2% of total electricity consumption per year in Western Europe and at the time it was projected to increase to 104 TWh per year by 2020. This is line with the US consumption of data centres representing 1.7% to 2% of US total electricity consumption (Koomey 2011). A more recent study identifies the following trends in Western Europe:

Table 1

Western Europe	2013	2014	2015	2016	2017	2018	2019	2020
Net data centre space (000 m2)	10,256	10,221	10,106	10,055	9,875	9,555	9,365	9,155
Average power (kW) per m2	1.1	1.1	1.2	1.2	1.3	1.3	1.2	1.2
Total power usage (GW)	11.3	11.2	12.1	12	12.8	12.4	11.3	10.9

Source: BroadGroup 2014

Table 1 shows a declining energy consumption in data centres in Europe due to consolidation, virtualization and energy efficient technologies especially in cooling. As seen in the table total net space decreases for different reasons including greater efficiency of data centres, user consolidation exercises, impact of virtualization, some space moving out of EU to lower cost locations, more outsourcing (to more efficient and shared infrastructure) and, particularly over the forecast period, further innovations in both IT and data centres.

From table 1 it can be derived a data centre consumption of 80 TWh or about 3% of total electricity consumption. It is interesting to note that another report (Datacentredynamics 2011) place total power consumption of data centres at 31GW, therefore Western Europe represent about one third of it.

Total net space decreases for reasons including greater efficiency of data centres, user consolidation exercises, impact virtualization, some space moving out of EU to lower cost locations, more outsourcing (to more efficient and shared infrastructure) and, particularly over the forecast period, further innovations in both IT and data centres

Why data centres?

Electricity consumed in data centres, including ICT equipment (servers, storage, network), cooling equipment and power equipment, is expected to contribute substantially to the electricity consumed in the European Union EU commercial sector1 in the near future. The projected rise in energy consumption poses a problem for EU climate and energy. It is therefore important that the energy efficiency of data centres is maximised to ensure the carbon emissions and other impacts such as strain on infrastructure associated with increases in energy consumption are mitigated.

In the EU there are policy actions for buildings, in particular the European Energy Performance of Building Directive (EPBD 2010), which imposes on EU Member States to adopt minimum efficiency requirements for buildings based on cost-optimality in their building codes. For equipment, the Eco-design Directive introduces common minimum efficiency requirements for end-use equipment such as domestic appliances, lighting products, consumer electronics, electric motors, air-conditioners, UPS, computers, servers, etc. In addition to the Eco-design directive, the EU has an agreement with the U.S. on the shared use of the Energy Star labelling programme. Energy Star equipment is available in Europe and it is promoted by public authorities as well as included in public authority's procurement.

It is important to note that data centres can occupy part of an existing building (e.g. one room or one floor), or fill an entire purpose built building. However the EPBD is not designed to improve the energy efficiency of data centres, as it only considers HVAC and lighting energy consumption. In most Member States, the EPBD introduces energy requirements in terms of kWh/m2/year as for "ordinary" buildings. The Eco-design Directive introduces efficiency requirements for individual equipment present in data centre such as UPS and servers (both not yet finalised at the time of writing the paper), however the selection of efficient equipment is not a per se guarantee that the data centre is efficient.

Historically, data centres have been designed with large tolerances for operational and capacity changes, including possible future expansion. Many today use design practices that are woefully outdated. These factors lead to power consumption inefficiencies. In most cases only a small fraction of the grid power consumed by the data centre is used by IT systems. Most enterprise data centres today run significant quantities of redundant power and cooling systems typically to provide higher levels of reliability. Additionally IT systems are frequently run at a low average utilisation.

Over provisioning, ensuring availability and associated costs were previously considered a negligible risk to business performance because energy costs were relatively small in comparison to the IT budget, and environmental responsibility was not considered to be the remit of the IT department. However, with rising energy prices this is no longer the case, and the issue of energy consumption at the individual data centre level is becoming increasingly important as operational energy expenditures and environmental impact of the energy consumed begins to play an ever important role in overall cost of ownership of data centres.

Preliminary evidence and the increasing willingness of manufacturers and vendors to compete on the basis of energy efficiency in data centres confirms that there are efficiency gains (e.g. using existing power management technologies) still to be realised without prohibitive initial costs that can lower the Total Cost of Ownership (TCO).

Businesses are also becoming increasingly aware of their environmental impacts and the need to reduce these. This is also the result of specific national energy efficiency polices implemented in some Members States such as the UK CRC Energy Efficiency Scheme, which is designed to improve energy

1 The commercial sector is also referred as the tertiary sector and it includes both private and public building hosting data centre. In this case energy consumption of data centres of companies in the industrial sector is included.

efficiency and cut CO2 emissions in large public and private sector organisations. The CRC affects large public and private sector organisations in different sectors, together responsible for around 10% of the UK's greenhouse gas emissions. Participants include supermarkets, water companies, banks, local authorities, all central government departments and data centres.

Many data centre operators are simply not aware of the financial, environmental and infrastructure benefits to be gained from improving the energy efficiency of their facilities. Even awareness does not necessarily lead to good decision making, simply because there is no framework in place for the operators to aspire to. Making data centres more energy efficient is a multidimensional challenge that requires a concerted effort to optimise power distribution, cooling infrastructure, IT equipment and IT output.

Many activities have been initiated within the industry2 and there are numerous vendor specific products and services offered. However, there is a risk of confusion, mixed messages, and uncoordinated activities. Independent assessment and coordination – tailored to European conditions such as climate and energy markets regulation – is required to lower the barriers of access to apply these energy saving opportunities.

The European Code of Conduct

Before introducing mandatory targets or legislation to improve energy efficiency in a hard to reach sector where several decision makers are involved and the potential for split incentives could hamper the decision to invest in energy efficiency, voluntary approaches could be explored. This may include voluntary agreements between public authorities and private enterprises. Voluntary agreements have proven to be effective in improving energy efficiency in Europe in different sector (Rezessy 2012). Voluntary agreements have also been particularly successful as a foundation for the Energy Star programme for buildings and industry.

In Europe, some voluntary programmes for the ICT sector have been introduced in the beginning of 2000, the Codes of Conduct. Now there are four Codes of Conduct in operation for ICT products: External Power Supplies, Digital TV systems, Broadband Equipment and UPS. These codes of conduct impose energy consumption limits or minimum efficiency criteria for specific products. Participation by equipment manufacturers is on a voluntary basis, but when the join any of the Code of Conduct they have to meet the performance level and report once a year on the energy consumption of the products they place on the market.

It has been decided to follow the same approach for improving energy efficiency in data centres. However it was not possible to have a minimum efficiency requirement for data centres given the diversity of data centres and the different level of responsibilities in data centres (some company being only responsible for the infrastructure, while other being responsible for the IT equipment selection and operation). In addition, a good metric to measure the data centre efficiency is not yet available (see discussion later on the paper).

Therefore it was decided that the key criteria for the data centre code of conduct was to ask participating companies to monitor their energy consumption and to adopt best practices.

For the purposes of the Code of Conduct, the term "data centres" includes all buildings, facilities and rooms which contain enterprise servers, server communication equipment, cooling equipment and power equipment, and provide some form of data service (e.g. large scale mission critical facilities all the way down to small server rooms located in office buildings).

Objective and aims of the Code of Conduct.

This Code of Conduct is a "multipurpose" document, allowing different stakeholders to commit to improve efficiency in their own areas of competence. The primary target of this Code of Conduct is the data centre owner / operator, who is encouraged to commit to undertake and implement energy efficient solutions in existing or new data centres, whilst respecting the life cycle cost effectiveness and the performance availability of the system.

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2 These include the US DoE, the US EPA Energy Star, the Green Grid association, Climate Savers Computing Initiative, the IEEE E-Server project

The Code of Conduct aims to:

- Develop and promote a set of easily understood metrics to measure the current efficiencies and improvement going forward in conjunction with other industry thought leadership fora.
- Provide an open process and forum for discussion representing European stakeholder requirements.
- Produce a common set of principles to refer to and work in coordination with other international initiatives
- Raise awareness among managers, owners, investors, with targeted information and material on the opportunity to improve efficiency3. Suppliers of efficient services and equipment, as well as other organisations4 can become allied in and endorsers of these targeted campaigns.
- Create and provide an enabling tool for industry to implement cost-effective energy saving opportunities
- Develop practical voluntary commitments which when implemented improve the energy efficiency of data centres and in so doing minimise the TCO.
- Determine and accelerate the application of energy efficient technologies.
- Foster the development of tools that promote energy efficient procurement practices.
- Support procurement, by providing criteria for equipment (based on the Energy Star Programme specifications, when available, and other Codes of Conduct5), and best practice recommendations
- Monitor and assess actions to properly determine both the progress and areas for improvement.
- Set energy efficiency targets, for public and corporate data centre owners and operators (targets are differentiated according to the size and status of existing data centres, the geographical location, the return on investments, etc.).
- Provides reference for other participants. The values of the Code of Conduct goes beyond the number of companies that sign and commit themselves, as the principles can be implemented also by other companies, which may not decide to make a public commitment. The existence of the European Code of Conduct introduces targets and guidelines which are open to every data centre.

The focus of this Code of Conduct covers two main areas:

- IT Load – this relates to the consumption efficiency of the IT equipment in the data centre and can be described as the IT work capacity available for a given IT power consumption. It is also important to consider the utilisation of that capacity as part of efficiency in the data centre

Facilities Load – this relates to the mechanical and electrical systems that support the IT electrical load such as cooling systems (chiller plant, fans, pumps) air conditioning units, UPS, PDU’s etc..

However the Code of Conduct will consider the data centre as a complete system, trying to optimise the IT system and the infrastructure together to deliver the desired services in the most efficient manner.

The Code of Conduct has both an equipment and system-level scope. At the equipment level, the Code of Conduct covers typical equipment used within data centres required to provide data, internet and communication services. This includes all energy using equipment within the data centre, such as: IT equipment (e.g. rack optimised and non-rack optimised enterprise servers, blade servers, storage and networking equipment), cooling equipment (e.g. computer room air-conditioner units) and power equipment (e.g. uninterruptible power supplies and power distributions units), and miscellaneous equipment (e.g. lighting). At system level the Code of Conduct proposes actions which optimise equipment interaction and the system design (e.g. improved cooling design, correct sizing of cooling,

3 This information could be disseminated through messages and information campaigns sponsored by governmental bodies at EU and national level, which are seen as independent and unbiased organisations.

4 e.g. the Green Grid association

5 e.g. the Code of Conduct for UPSs.

correct air management and temperature settings, correct selection of power distribution), to minimize overall energy consumption.

Data centre owners and operators can join the Code of Conduct by becoming Participants by committing to implementing the recommended Best Practices with an indicative timeline and regularly reporting the result achieved. Though not entailing legally binding obligations, Participant status requires strong commitment and a substantial contribution to the objectives of the Code of Conduct. Each participant will set the areas of responsibility (defining which parts of the data centre they are responsible for implementing the efficiency improvements), the coverage (defining the data centres / building / sites at which energy efficiency actions will be undertaken) and the nature (specifying the actions that the enterprise proposes to carry out at each location) of its commitment.

Many data centres operators do not control the entire data centre but still may participate in the Code, for example colocation operators or their customers. In order to include these operators as Participants their partial control is recognised and they should implement the practices that fall within their control and endorse the practices outside of their control to their suppliers or customers as appropriate.[6]

Participants are grouped into categories according to which parts of each data centre they have control over and responsibility for possible efficiency improvements;

Operator
Colocation (Colo) Provider
Colo customer
Managed service provider
Managed service provider in Colo

Efforts to improve efficiency differ in the level of commitment and investment ranging from simple energy management practice and low cost solutions, to exploring alternative, energy efficient opportunities before specifying or replacing IT equipment and supporting infrastructure, to designing new highly efficient data centres or upgrading existing ones to very high level of efficiency. Participants are expected to select, adopt and implement a subset of the recommended best practices.

For existing data centres, Participant application starts with an initial energy measurement of at least one month and energy audit or assessment to identify the major energy saving opportunities. The applicant should prepare an Action Plan and supply a completed Reporting Form with their application. The reporting form should identify the best practices already implemented and those to be adopted within three years of the application date with a description of the action plan to achieve this.

From 2010 onwards, new data centres (under construction or recently completed) should identify in the Reporting Form the practices adopted to make the data centre "best in class" for their application. New data centres should implement all of the expected practices applicable to the type of operator including those identified for build or retrofit 2010 onwards from the date of application and should not require an action plan and a refurbishment to achieve Participant status.

Data collection

In order to qualify as a Participant, applicants must submit the Reporting Form describing simple physical and operational characteristics of the data centre, and the most recent one month facility and IT energy consumption data. Participants will then log the Facility and IT energy consumption at least monthly. This should then be reported once per year. At a minimum, the facility energy will be measured at the utility for a stand- alone data centre, or the data centre sub meter. IT energy consumption is measured at the UPS outputs. Some operators may not be able to immediately obtain the full facility energy consumption, for example an operator whose data centre is in a shared office building and uses the “house” chilled water system for cooling may not be able to meter the data centre part of their cooling system energy consumption. Operators unable to provide both the total facility energy and IT energy should provide the information available and an action plan to achieve metering where feasible.

Operators in a shared building who have a shared power delivery path or shared HVAC system and insufficient metering to be able to extract and report the facility energy should: i) provide an explanation of the issue preventing metering of the facility energy; ii) provide IT electrical energy

6 See the Best Practice guide for further details of the Practices, types of operator and areas of responsibility.

measurements; iii) present an action plan to improve the metering; and iv) provide any meter data available for the building including a description of exactly what parts of the data centre or other loads are on each meter.

Metrics

In common with other industry bodies, the Code of Conduct initially used the ratio of IT Load to Facilities Load as the key metric in assessing infrastructure efficiency. This is known as ‘facility efficiency’. The Code of Conduct is also concerned with the efficiency with which the IT equipment utilises the power delivered, this will be known as ‘asset efficiency’. The Code of Conduct aim at adopting more comprehensive metrics which may also cover the IT system design, the IT hardware asset utilisation, and the IT hardware efficiency.

The European Code of Conduct decided to use available metrics, such as power usage effectiveness metric (PUE) and to contribute to the definition of additional metrics, through the International Taskforce7 for the Harmonisation of Metrics for Data Centre Energy Efficiency. The Task Force in 2011 specified a detail measurement protocol for PUE. In October 2012, the Taskforce provided measurement guidelines for three additional metrics: green energy coefficient (GEC), energy reuse factor (ERF), and carbon usage effectiveness (CUE).

The Taskforce further worked on effective energy efficiency metrics that measure the actual IT work output of the data centre compared to its actual energy consumption. For this, the task force recommended that a data centre defines attributes and measure data centre energy productivity (DCeP) according to the following: DCeP is an equation that quantifies useful work that a data centre produces based on the amount of energy it consumes. DCeP is computed as useful work produced divided by total energy consumed by the data center.

As this was a very complex task the Taskforce also worked on metrics to measure the potential IT work output compared to expected energy consumption, and to measure the operational utilization of IT equipment. To this end the Taskforce studied a wide range of proxies for data center productivity and has narrowed the field to three proxies that each addresses this outcome in a different way, however no agreement was reached in endorsing and recommending any of the three proxies.

Results and analysis

Up to the time of writing this paper, 263 data centres have applied for Participant Status and 224 have been approved as Participants. 87 organisations have at least one DC approved as Participant. In Europe there are participants in 21 countries: Portugal, Spain, France, Italy, Switzerland, Austria, Romania, Greece, Hungary, Poland, Malta, Finland, Sweden, Denmark, Netherlands, Germany, Belgium, Luxemburg, UK, Turkey and Ireland. One Participant is outside Europe with 4 DCs in the U.S.. Based on the data submitted by the Participant the following analysis is provided. The Code of Conduct covers 3.2 TWh of electricity consumption, which is between 3 to 5 % of the total data centres consumption in Europe. The majority of data centres (57%) are stand-alone data centres. In terms of the sector covered, the traditional enterprise is the dominating sector followed by hosting.

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7 The following organisations participate in the Task Force: the U.S. Department of Energy’s Save Energy Now and Federal Energy Management Programs (March 2009 – October 2012); the U.S. Environmental Protection Agency’s ENERGY STAR Program; the European Commission Joint Research Centre Data Centres Code of Conduct; Japan’s Ministry of Economy, Trade and Industry; Japan’s Green IT Promotion Council; and The Green Grid.

Table 2. Average data

Total dataset	221	
Total annual electricity consumption	3 223 500 00	MWh
Average DC floor area	2 500	m2
Average Rated IT load	1 900	kW
Average annual electricity consumption	14 400	MWh
Average PUE	1.77	
Average high temp setpoint	24.3	degC
Average low temp setpoint	20.2	degC
Average high humidity setpoint	62.4	% RH
Average low humidity setpoint	33.4	% RH

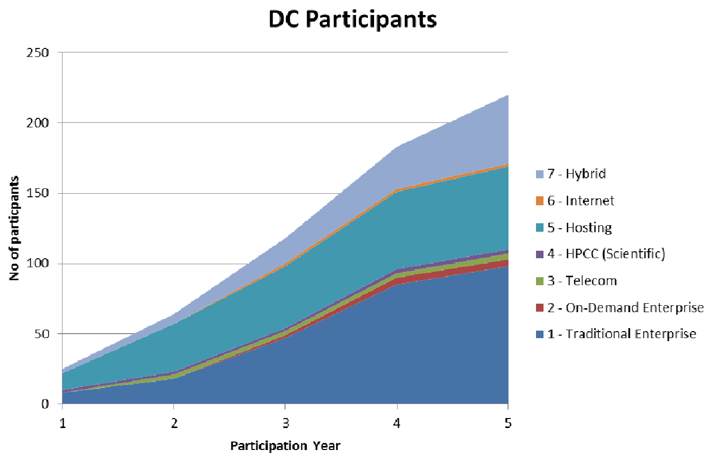

Figure 1

By analysing the data reported we can see an increase of efficiency over time (only the initial data reported has been analysed, i.e. subsequent annual energy consumption reports have not been included). In 2013 the, average efficiency is around a PUE just under 1.7. It is worth noting that the Digital Realty Trust Campos survey published in January 2013 found Europe average PUE is 2.53 (2.62 the previous year).

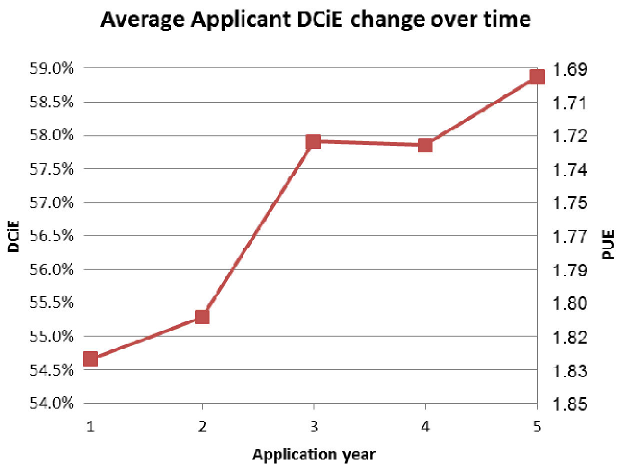

Figure 2

A more detail analysis (figure 3) shows that Efficiency is slowly increasing with a slow decline in the least efficient data centres, particularly those with PUE worse than 2 and recently a more even spread in efficiency distribution with PUE between 2 and 1.43, rather than very clear peaks in early years.

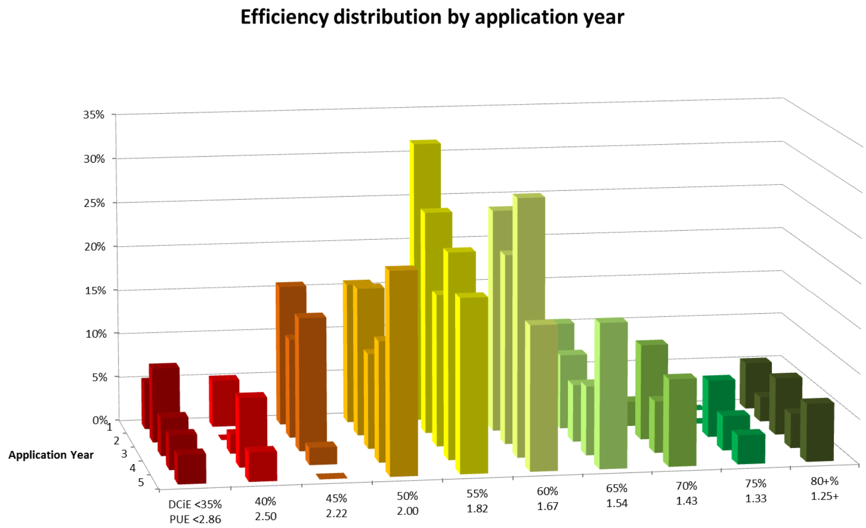

Figure 3

Two other important parameters supplied by participants, i.e. temperature and humidity set points have been analysed. The Code of Conduct place a lot of emphasis on raising the temperatures set point (the Best Practices document recommend that data centres are designed and operated at their highest efficiency to deliver intake air to the IT equipment within the temperature range of 10°C to 35°C and with a wide range of humidity). From the data reported, the relative humidity is diverging (figure 4, this graph doesn't show DCs with no humidity control with is now becoming more common), while it is not possible to detect any change over time for the high temperature setpoint which seems to be fairly constant at around 25 degC.

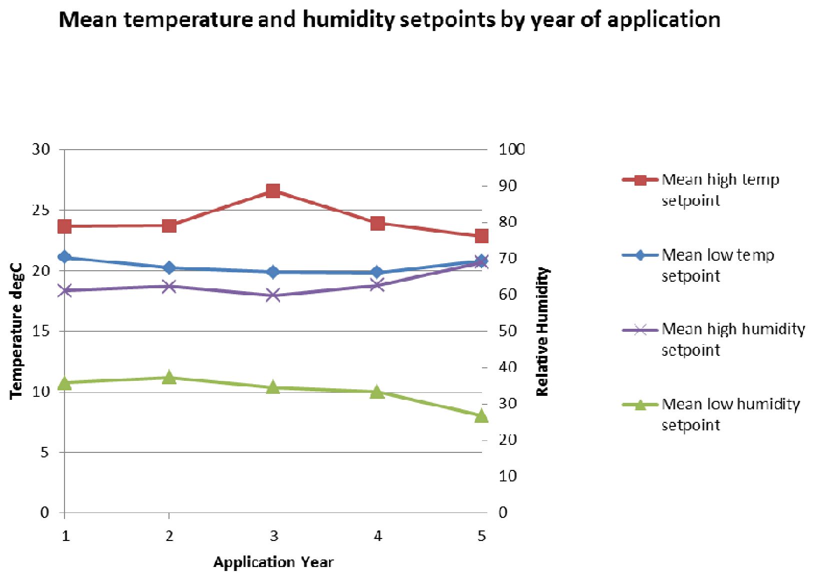

Figure 4

The analysed data shows that there is a small correlation between the PUE and the upper temperature set point.

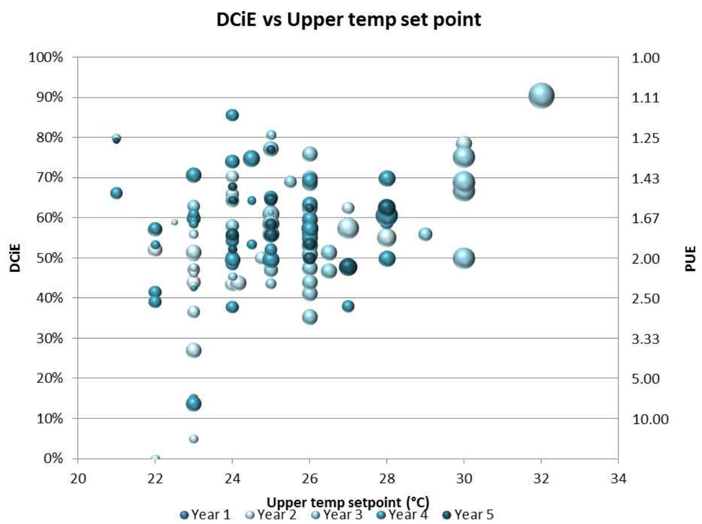

Figure 5

In the past year the Code of Conduct started collecting information on the types of economisers being used. This is a relatively small dataset of 80 or so DCs. In figure 6 the bar graph shows the proportion of data centres using each type of economiser. The high-low line shows the min and max DCiE while the cross shows the average. Around 55% of DCs use an economiser of some sort. If it wasn't already clear, it shows it's definitely a mainstream technology. Encouragingly water chillers and DX appear to be able to achieve very high efficiencies with a min PUE of 1.17. The big improvements in efficiency don't seem to be fully realised with economiser use. However, we need to bear in mind this is a very small dataset with only four DCs using direct water side economisers that have been operating long enough to collect data. What it does show is there's more to efficiency than just installing an economiser.

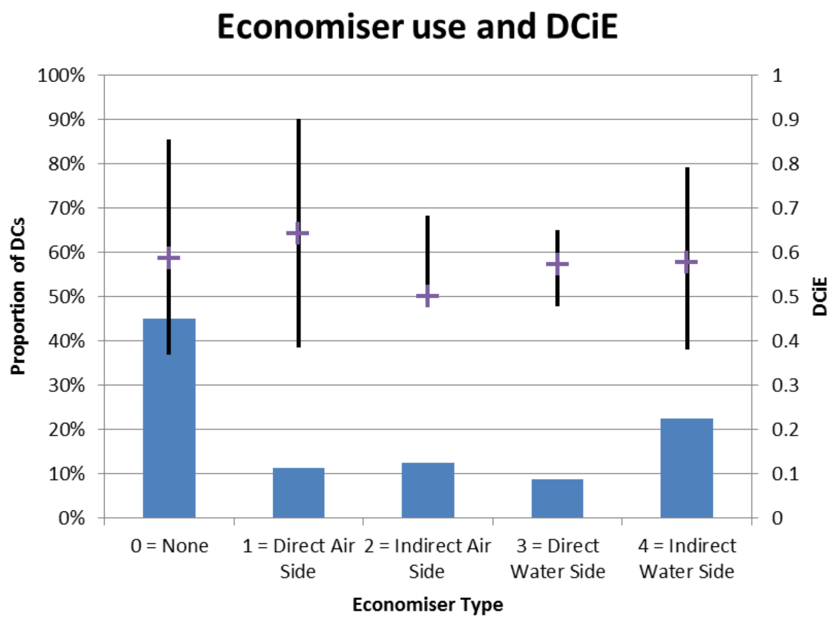

Figure 6

An in depth analysis of the best practices adopted has been carried out on a reduced sample of 49 data centres. The Top Implemented Best Practices are in the table below. It is clear that the majority of the top implemented practices are those that do not require capital expenditure or major changes to business practices, indeed all of the practices could be considered to be the "low hanging" fruit.

Table 3

Best Practice	Brief Description	No of Implementations
3.1.1	Group Involvement	49
3.3.1	Build resilience to business requirements	49
3.3.3	Lean Provisioning	49
3.3.4	Part Loading	49
5.1.1	Design Contained Hot/Cold	49
5.1.2	Blanking Plates	49
5.1.8	Design Hot/Cold	49
5.1.11	Perforated Doors	49
6.1.2	High Efficiency UPS	49
7.1.1	Turn off lights	49
7.1.2	Low Energy Lighting	49

9.1.2	IT Energy Consumption Meters	49
9.2.1	Periodic Manual Readings	49

The lowest implemented Best Practices are in table 3 below.

Table 4

Best Practice	**Brief Description**	**No of Implementations**
4.1.6	Power Management	39
4.2.4	Select Efficient S/W	41
4.2.5	Develop efficient S/W	42
5.2.3	Review Cooling	42
5.2.4	Review Cooling Strategy	43
6.1.3	UPS Operating Modes	41

"Enable Power Management Features" was the worst performing practice. There are a number of reasons why applicants have not implemented this best practice. These include:

colocation providers who do not have direct control over hardware settings;

the perception that these features introduce IT instability;

colocation providers that are not effectively endorsing the Code of Conduct formally or informally to clients;

some businesses that cannot allow the downtime required to implement the best practice at a hardware level; and

technical staff that are not aware of the nuances of power management and how it will effect normal operation or are unaware that there are power management features and services available.

The selection of efficient software is problematic as no software markets itself as being “energy efficient”, however it seems that many organisations have developed procurement clauses that would require an “energy efficient software” decision point. In some cases, the use of virtualisation software or work stream dynamically control resource software is being used. Some applicants, such as colocation providers, do not have control over the selection of software.

In the absence of global “green coding” guidelines or standards, it is difficult for applicants to understand and implement the practice "Develop efficient software", however green coding is gaining ground and workshops are available in certain countries. It may be the case that a general “coding” best practice includes energy efficiency techniques.

Many of the applicants not implementing the best practice "Review Cooling" are colocation providers, stating that they are reliant on customers informing them of equipment changes.

Concerning "Review Cooling Strategy", most of the applicants cite that there is a balance between energy efficiency and operational requirements. There are two main reasons why the best practice "UPS operating modes" has not been implemented, these are: that the UPS installed in the facility does not have an “eco mode” or the “eco mode” itself does not provide sufficient rapid fail over for use within the facility.

Conclusions

The Code of Conduct is the only independent pan European scheme in the EU to certify that a data centre has adopted energy efficiency best practices. There is increasing interest for the Code of Conduct among data centres operators. It is still too early to evaluate the overall impact of the Code of Conduct on energy savings. The best practices implementation shows that the most cost-effective and short payback period measures are mostly implemented. Through the collection of the data centres energy consumption (total facility and IT load) we will be able to track efficiency improvement over time. The dataset of over 200 data centres with the energy data and the technologies adopted provided a very interesting data set for further analysis. There are already a number of showcase data centres with PUE below 1.2 which have gained the Annual Award for the best implementations (both for new and retrofitted data centres). The Code of Conduct has received positive feedback from participants and industry (with over 200 companies that have endorsed it). With the feedback provided by participants, the Code of Conduct will be improved through communication with market actors and the outreach activities will be further strengthened in 2014 in order to substantially increase the number of participants.

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Session

Energy Retrofit

Energy retrofit of tertiary buildings by installation of a double PCM wallboard: Sensitivity analysis for common European climates

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Abstract

The European Commission, in the communication COM (2011) 112 - "Roadmap for moving to a competitive low carbon economy in 2050" - fixed a decrement around 80% of greenhouses emissions compared to the 1990 levels. About it, the building sector has high potentialities for reducing its energy demand and related pollution. More in detail, the attention should be focused on both new buildings and - mainly - at the energy-oriented refurbishment of the building stock.

Several studied are available about possibilities for reducing the winter energy demands of buildings. In particular, both building envelope and HVAC systems could improve own energy performances, by adding thermal insulation at the opaque structures, by installing suitable transparent systems, by using efficient heat generation devices and insulated hot/chilled water loops. However, each measure must be carefully analyzed, being possible also that too low values of thermal transmittances imply negative hyper-insulation effects during the cooling season, above all in buildings of tertiary sector, characterized by high endogenous energy gains.

In order to reduce the energy demands for the microclimatic control, during both heating and cooling seasons, this paper tries to propose guidelines for design and optimization of new passive technologies, such as the phase change materials (PCMs). More in detail, the energy, environmental and economic impacts of a double layer of PCM wallboard, adopted as energy efficiency measure, will be investigated for a case study building, assumed as typological of the European building stock. The behavior of the building - used for retail at the ground floor, warehouse at the first level and dwellings on third floor - has been simulated with EnergyPlus, according to climatic conditions typical for various European climates.

Introduction: energy savings in the building sector

The potential for achieving energy savings in the building sector is widely recognized. The building energy requests have a share around 41% of energy demanded at EU level in 2010, with an impact of around 27% of residential buildings. The space heating has the highest share in the total energy consumption of the tertiary sector. It accounts for more than 70% in Germany and for around 60% in France. Furthermore, with reference to the EU countries [1], in the last years, the electricity request has increased very rapidly, especially for information/communication technologies and air-conditioning uses, starting from a share of 31% in 1990 until a share of 43% in 2009.
The Energy Performance of Buildings Directive (EPBD, Directive 2002/91/EC) has been the main EU policy tool aimed at improving energy performance of buildings [2]. The new version of the Directive, by means of the recent EPBD Recast (Directive 2010/31/EC), requires that Member States fix minimum performance requirements for new buildings and for buildings undergoing major renovation "with the view to achieving cost optimal levels". The Recast Directive establishes a strong focus on the existing building stock, encouraging Member States in promoting and supporting energy refurbishments and in setting higher standards for buildings undergoing retrofitting [3].

According to these international energy saving targets, new building envelopes and the refurbished structures of existing constructions have high level of thermal insulation. However, in order to improve the thermal characteristics of opaque elements of the building envelope, with a reduction of the energy demand, also innovative technologies can be usefully adopted.

In a large literature review, Soreas *et al*. [4] showed that building elements with Phase Change Materials (PCMs, in the following sections of the paper) provide a good potential for reducing energy demands for heating and cooling, because of the lower dynamic thermal transmittance. The same solutions can also improve the indoor comfort. More in detail, passive technologies - such as the incorporation of PCMs into traditional walls - could allow a heat transfer control, inducing time lag and attenuation of the heat wave crossing the building structures.
This paper will propose a deepening concerning the effects of a double layer of PCM wallboard adopted as energy efficiency measure, with reference to a case study building with massive and insulated structures. The main motivation of the study is to quantify the achievable annual energy savings and to verify the potential of these materials for improving the energy performances of existing architectures, by taking into account various European climates. The dynamic behavior of the building, assumed as typological of the building stock, has been simulated with EnergyPlus v.8.1.0 [5], adopting the "one-dimensional conduction finite difference (ConFD)" algorithm, instead of traditional algorithms based on the CTS (Conduction Transfer Function). Indeed, this method cannot be adopted for energy studies regarding the phase changing of materials, being the thermal field within the structures not completely developed.

Use of PCM to improve building's thermal performance

The latent heat storage – with the incorporation of PCMs into building materials for ensuring thermal inertia, in addition to the use of thermal insulation and shading systems - allows the reduction of the winter heat losses and summer heat gains. In winter, the use of PCMs allows the storage of thermal energy in the building envelope, while, in summer, the phase change reduces the cooling loads because of the melting of the material (that requires energy). Of course, a proper night cooling, suitable for discharging the PCM, is highly recommended in the warm season. All told, the use of PCMs can reduce the indoor temperature fluctuations as well as the indoor peak temperatures, by improving the indoor comfort conditions with a contextual reduction of energy requests for air-conditioning [6]. In recent years, thermal energy storage systems, using phase change material (PCM) in buildings, are widely investigated and under a fast development. In this section, it will be presented a short review of the main results of the scientific research, as well as the simulation tool used in this paper.

The use of PCM in building applications

PCMs are characterized by phase change phenomena (melting and solidifying), occurring at a temperature value or range, and it allows storage of latent heat. Recently, Pomianowski *et al*. [7] summarized many research studies, by focusing on the identification of methods suitable to determine correctly the thermal properties of PCM materials and their composites, as well procedures to evaluate their latent storage capability and thus the energy saving potentials.

Izquierdo-Barrientos *et al*. [8] concluded that there is not an evident optimum temperature for minimizing thermal flows crossing the walls with reference to both the heating and cooling seasons. With reference to the sole cooling season, the choice of a low melting temperature leads to an under-utilization in the months characterized by the most critical conditions. On the other hand, a melting temperature too high may result in a poor efficacy in the central cooling period. A possible optimization consists in the installation of two layers of PCM with different melting temperature. Jin and Zhang [9] studied the thermal performances of a double layer of PCMs, by means of a dedicated numerical model. The authors identify an optimal melting temperature.

Diaconu and Cruceru [10] evaluated the performances of a wall system made with a three-layer sandwich-type insulating panel, with outer layers consisting of PCM wallboards and middle layer composed of conventional thermal insulation. The new wall system allows about 1% of energy saving in summer and 12.8% of energy saved in winter. Recently, a simplified dynamic building model was proposed and validated for a new wall system. This is a three-layer sandwich-type panel with outer layers consisting of PCM wallboards and middle layer consisting of conventional brick. Each layer of the composite wall has an identified function: the external layer has a higher PCM melting temperature and it works in summer, while the internal layer has a PCM melting temperature close to the indoor set point fixed for the winter. Zhu *et al*. [11] concluded that this study could be considered a starting point for a numerical investigation aimed at confirming the technical feasibility of the new wall system.

Most of the literature studies propose PCM systems numerically or experimentally optimized exclusively with reference to the winter or summer necessities. Only few studies have been carried out about the PCM performances by taking into account the entire year. In all papers, it's clear the improving of thermal comfort that the passive use of PCMs in buildings can induce. Diversely, not many results are available about the consistency of annual energy savings for heating and air conditioning under reliable conditions of internal loads. Typically, passive systems are studied without including in the analysis the heat losses and gains through ceiling/roof, floor and windows, as well as air infiltration, ventilation, and gains due to occupancy. These aspects are often neglected [12] and, as underlined by Ascione *et al*. [13], these contributions become very significant on the performance of the phase change materials, since these affect the frequency of cycles and the time interval necessary for reaching the melting point.

Starting from the aforementioned considerations, this paper is aimed to study the effect of the application, on vertical walls, of two PCMs with different thermo-physical properties, suitable for non-invasive building refurbishments. In most of the current scientific researches, the use of PCMs is associated mainly to "lightweight" structures, while this paper investigates the benefits achievable on masonry heavyweight solutions, typical of the European building stock. The main target of the simulation is to quantify energy savings and analyze the influences of the phase change temperature and of the location of the PCM layers with reference to the annual energy demand of a building. Moreover, PCM is evaluated also with reference to its capability in improving the indoor microclimate. The dynamic behavior of the building will be studied by considering the effect of internal loads, occupancy patterns and ventilation. The study of the effect of the addition of two PCM layers is evaluated in five European cities (Naples, Bordeaux, Frankfurt, Stockholm and Copenhagen), through the presentation of a case study. These climates have been chosen because representative of the variability among the EU States. Chwieduk [14] verified that, in countries characterized by high latitudes, if a PCM composite layer is integrated into a wall structure, there is always a need of thermal insulation as external layer of the opaque elements of the building envelope. The selected locations allow to verify that - for the PCM optimization in composite walls - the other materials play a significant role and these (e.g. mortar, brick, reinforced concrete) should be considered as part of the passive system. Finally, the entire structure should be considered in the design phase.

It should be noted that - in order to predict the overall energy consumption - it is essential to have models suitable for estimating the cooling/heating demands of the building. Several approaches are available for modeling the transient heat storage during the phase change of the material, as - for instance - the "effective heat capacity method" or the "enthalpy method". In this regard, many studies have attempted to validate the energy simulation by the use of commercial software developed in order to describe the physical phenomena of the PCM operation. In this paper, dynamic energy simulations have been performed by means of a well-accredited program for the building energy simulations: Energy Plus v.8.1.0.

The PCM model in EnergyPlus

Kuznik and Virgone [15] and Tardieu *et al*. [16] compared the EnergyPlus simulation results to experimental data, and they verified a good agreement. Tabares-Velasco *et al*. have verified and validated the PCM model in EnergyPlus for PCM distributed in drywalls, in fibrous insulation and for a thin-concentrated PCM layer [17]. Starting by this literature, EnergyPlus was used as simulation tool also in the present study, by taking into account the recommendation expressed in [17]: a) the simulation time step should be shorter than three minutes, b) PCM materials with not strong hysteresis should be adopted, c) small node spaces for accurate hourly analyses are required.

In this paragraph, the physical method is briefly described. EnergyPlus allows the use of two different formulations for PCMs. The first one is based on the Crank-Nicholson scheme (equation 1), considered as second order in time. The second one is the fully implicit scheme (equation 2), considered as first order in time. The specific heat of material (C_p) is variable and it is updated with reference to any numerical iteration, according to equation 3.

$$C_p \rho \Delta x \frac{T_i^{j+1} - T_i^j}{\Delta t} = \frac{1}{2}\left[\left(\lambda_w \frac{T_{i+1}^{j+1} - T_i^{j+1}}{\Delta x} + \lambda_E \frac{T_{i-1}^{j+1} - T_i^{j+1}}{\Delta x}\right) + \left(\lambda_w \frac{T_{i+1}^{j} - T_i^{j}}{\Delta x} + \lambda_E \frac{T_{i-1}^{j} - T_i^{j}}{\Delta x}\right)\right] \quad (1)$$

$$C_p \rho \Delta x \frac{T_i^{j+1} - T_i^j}{\Delta t} = \left(\lambda_w \frac{T_{i+1}^{j+1} - T_i^{j+1}}{\Delta x} + \lambda_E \frac{T_{i-1}^{j+1} - T_i^{j+1}}{\Delta x} \right) \quad (2)$$

$$C_p = \frac{h_{i,new} - h_{i,old}}{T_{i,new} - T_{i,old}} \quad (3)$$

With reference to the above-reported equations, the subscripts indicate:

- "i" the modeled node;
- "i+1" the adjacent node in the direction of the internal side of the construction;
- "i-1" the adjacent node in the direction of the external side of the construction.
- "j+1" the new time step and "j" the previous one.

Moreover, "T" indicates the node temperature; "Δt" and "Δx" are respectively the calculation time step and the finite difference layer thickness; ρ is the density of material; "λ_w" and "λ_E" indicate respectively the thermal conductivity for the interface between nodes "i" and "i+1" and for the interface between the nodes "i" and "i-1". It is also possible to take into account a variable thermal conductivity. The algorithm uses an implicit scheme of conduction finite difference (CondFD) combined with an enthalpy-temperature function. Hence, the definition of the "*h-T*" curve, starting from catalog data (i.e., when the simulations concern commercial PCM wallboards) is necessary.

Description of the case study

This is a three storeys building, with rectangular shape and an overall height of about 10.5 m. The net conditioned building area is 685.5 m^2. The “surface" to "volume" ratio (S/V) is equal to 0.54 m^{-1}. Table 1 shows, for each facade, the gross wall area and the window-wall ratio for the entire building.

Table 1: Geometrical description of the building vertical envelope

	Total	North	East	South	West
Gross Wall Area [m^2]	904.6	371.9	80.5	371.9	80.5
Window Opening Area [m^2]	172.4	23.21	1.99	145.2	1.97
Window-Wall Ratio [%]	19.1	6.24	2.48	39.1	2.45

Characterization of building uses and definition of thermal zones

According to [1], retail and wholesale trades represent the largest proportion of non-residential buildings, with 28% of the floor space. Office buildings are the second largest category with around 25% of the total non-residential floor space, followed by educational buildings (20%), hotels and restaurants (11%), hospitals (7%), sport facilities (4%) and others destinations of use (5%). Thus, a common configuration of retail/residential buildings, in a European city center, has been chosen, according to common building typologies. In Figure 1, the case study building is represented.
As aforementioned, the modeled building has three available storeys. At the ground level, it is used for four clothing stores with private warehouses on the first floor. At the second floor, instead, there are two apartments with two bedrooms, two bathrooms and a living room with an open kitchen. The building has also common circulation areas, such as the stair block just outside the apartments.
In order to define reliable thermal loads, nine typologies of thermal zones have been created (Table 2) according to classifications and requirements specified by the Italian Standard UNI 10339 [18].

Table 2: Main data concerning the simulated building - Thermal Zones.

Zone	People [person/m^2]	Internal Load [W/m^2]	Lighting power [W/m^2]
Toilet store	0.10	3.00	5.0
Workshop	0.10	8.00	8.0
Warehouse	0.05	3.00	5.0
Stairways store	0.05	2.00	5.0
Circulation	0.05	2.00	5.0
Bathroom	0.10	3.00	5.0
Bedroom	0.04	4.00	5.0
Kitchen	0.10	10.0	5.0
Domestic Lounge	0.04	4.00	5.0

The Air Change Rate has been fixed to 1.5 h^{-1} for the store's zone and to 0.8 h^{-1} for the dwelling's zones, in order to guarantee the required comfort conditions fixed by the standard UNI EN 15251 [19]. More in detail, the Category II has been considered, with an expected percentage of dissatisfied equal to 20%.

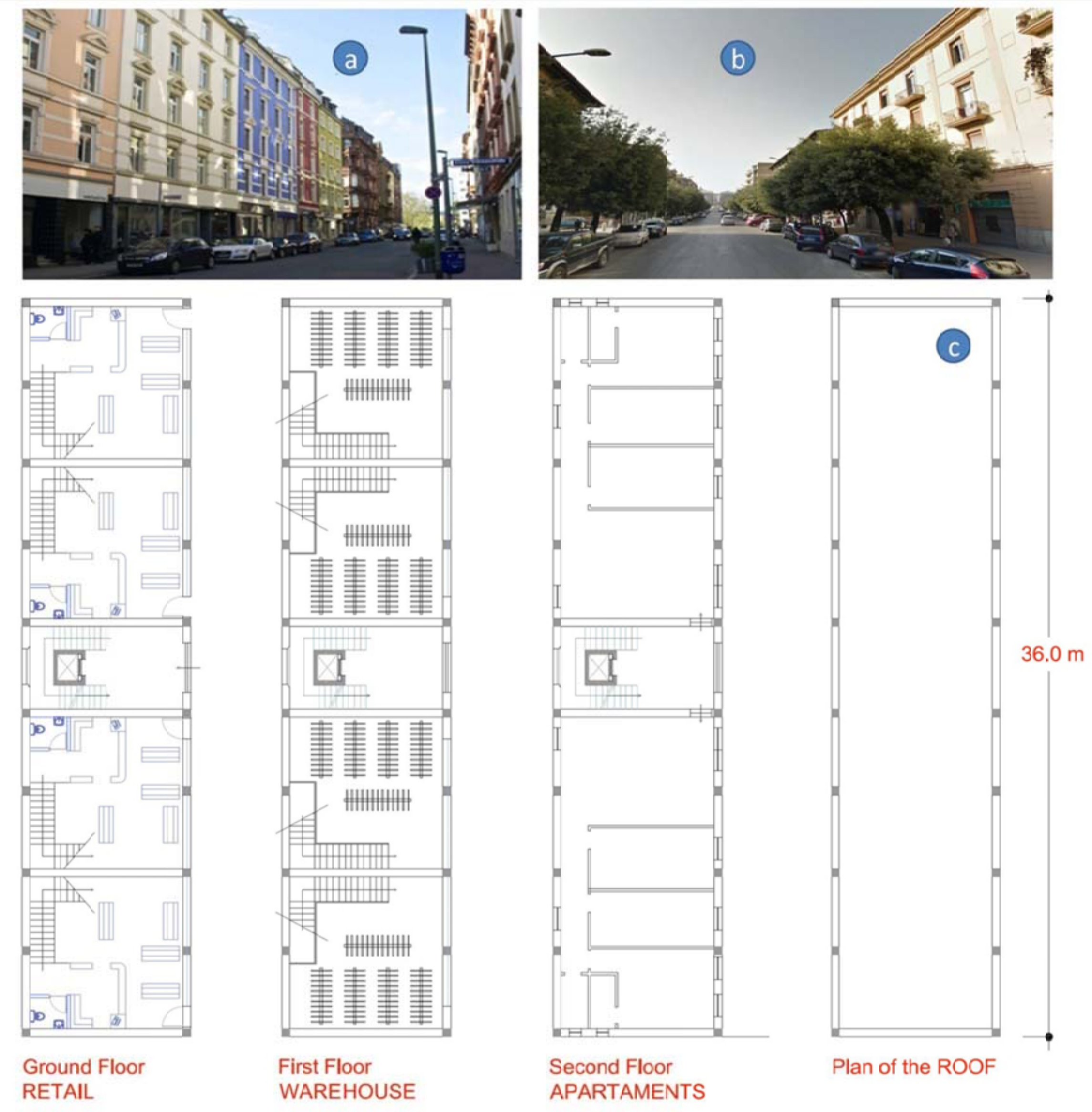

Figure 1: Examples of typical configurations of retail/dwelling buildings, in European city center: a) Brückenstraße in Frankfurt am Main and b) Viale Principe di Napoli in Benevento (*source: Google Street View*), and c) the case study building

Computational boundary conditions

As previously cited, the building performances have been simulated in Naples (Italy), Frankfurt am Main (Germany), Bordeaux (France), Copenhagen (Denmark), Stockholm (Sweden). These cities are characterized by different climatic conditions, and thus the variability of climates of European Countries is well-represented. The aim, indeed, is the quantification of achievable annual energy savings and evaluation of PCMs potential in building refurbishments, for different climatic conditions. In this way, it is possible to investigate the efficiency of PCMs in multilayered structures, characterized by high thermal resistance at high latitudes and by medium thermal resistance in Mediterranean climates (e.g. Naples, where commonly the cooling demands are comparable or higher than the heating requests). Synthetically, according the climate classification of Köppen [20]:

- Bordeaux is representative of an oceanic climate, even if the summers tend to be warmer and the winters get milder compared to most areas of similar classification.
- Copenhagen has a typical oceanic climate.
- Frankfurt has a temperate oceanic climate, with moderately cold winters and warm summers.
- Stockholm has a humid continental climate.
- Naples has a Mediterranean climate, with mild, wet winters and warm, dry summers.

Construction Solutions

The simulated building has been modeled according to common building technologies of the European tradition after the Second World War, with a wide use of reinforced concrete for the structural parts (i.e., pillars, beams and joists) and hollow clay blocks for the opaque vertical envelope. The geometrical and thermo-physical characteristics of the modeled materials are reported in Table 3.

Table 3: Physical properties of wall layer

	dx	C_p	λ	ρ
	[m]	[J/kg K]	[W/m K]	[kg/m^3]
Internal plaster	0.02	1000	0.70	1400
Hollow blocks	0.40	1000	0.15	1000
Insulation in XPS	variable	1400	0.035	25
External plaster	0.02	1000	0.90	1800

The horizontal structures (and thus basement on the ground, floors and ceilings) have mixed bricks/reinforced concrete layers. It has been assumed that all exterior structures are thermally insulated, during a previous refurbishment, by means of panels in expanded polystyrene (EPS). The insulation thickness has been differentiated in order to simulate the building stock of the different European regions. For high latitudes, the insulation layer has been chosen with a thick suitable for limiting the heat losses in winter, due to the high temperature difference between outdoor and indoor environments. The insulation thickness and the transmittance (U) values for the different cities are summarized in Table 4. As said, the U_{VALUES} are referred to refurbished buildings. Thus, our study will concern a further energy efficiency measure, quite innovative, consisting in the addition of two phase change materials.

The partition walls are lightweight; these have two plasterboards with an air gap interposed (U_{VALUE} = 1.64 W/m^{2}K). About the windows, these are double glazed (4 mm uncoated glass / 12 mm argon cavity / 4 mm uncoated glass) with metallic frame with thermal break and exterior blinds. An overall thermal transmittance equal to 2.55 W/m^{2}K has been calculated. The window typology has not been differentiated in order to avoid a further parameter affecting the simulation results. However, the U_{VALUE} is quite suitable for all the considered climates.

In the following sections of the manuscript, the above-described reference building will be named "N_PCM".

Table 4: Insulation thickness and transmittance values for wall and roof/floor

Cities	dx [m]	U_{VALUES} [W/m^{2}K]	
	EPS	Wall	Roof/Floor
Bordeaux	0.10	0.17	0.28
Copenhagen	0.20	0.12	0.15
Frankfurt Main	0.15	0.14	0.20
Naples	0.05	0.23	0.46
Stockholm	0.25	0.10	0.13

System and equipments for the space heating and cooling

The building has a hydronic air-conditioning system, for both the space heating and the summer cooling. Four pipe fan-coils are used for the sensible loads' control in both the seasons, with hot water produced by a condensing gas boiler and chilled water provided by an air-cooled chiller (energy efficiency ratio, at rated conditions, equal to 3.1 $W_{THERMAL}/W_{ELECTRIC}$).
In winter, the stores are heated at 20 °C, in the working hours (i.e., from 10.00 to 20.00), every days. In summer, the cooling set-point is at 26 °C, with the same operating hours defined for the space heating.
According to the same set-point temperatures, the dwellings are heated from 6.00 to 9:00 and from 16:00 to 23:00. In summer, the apartments are cooled from 16.00 to 22.00, and thus only in the afternoon/evening.
Finally, conventional heating and cooling periods have been considered in order to compare the efficiency of the retrofit actions with reference to the same operational conditions in the various countries. The heating period has been assumed starting from the 15 November and ending at 31 March. Of course, in cold regions, the heating periods can be longer. About the cooling period, this begins in the middle of May and finishes at the end of September.

Retrofit solutions

The retrofit solution consists in the replacement of the internal and/or external plaster of all vertical facades with two PCM plasters with different functions:

- the first one, indicated as "PCM_H", has a melting point close to the set point temperature for heating and it is active during the cold season;
- the second one, named "PCM_C", has a higher value of the PCM melting point and it is active during the hot season.

This study would investigate real commercial products. Therefore, the considered gypsum plasterboards have been chosen according to the market availability. Their main characteristics are reported in Table 5.

Table 5: Physical properties of investigatedPCM plasters

	T_f	ΔH_f	C_p	λ
	[°C]	[kJ/kg]	[J/kg K]	[W/m K]
PCM_H	20	24.5	1200	0.7
PCM_C	26	110	1400	0.3

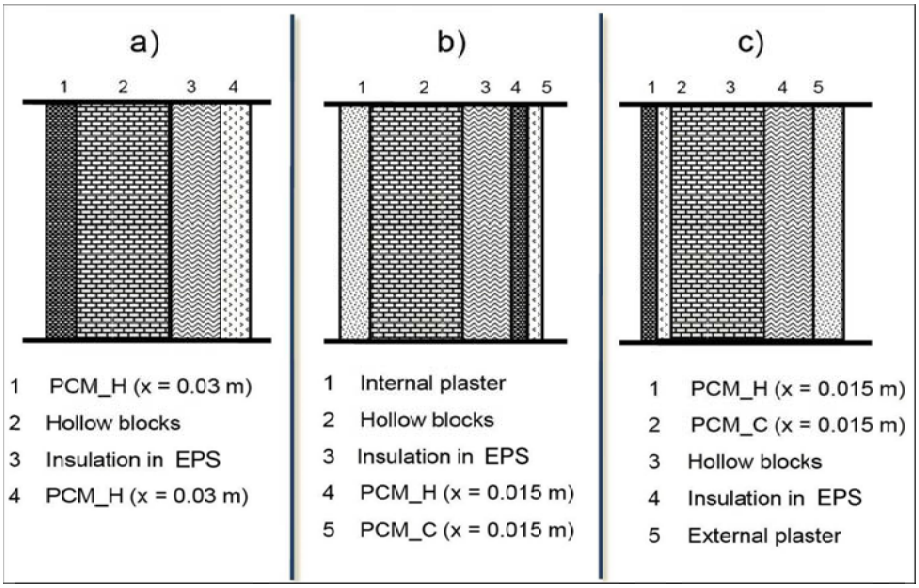

Figure 2: Simulated configurations for the position of the PCM layers

As above indicated, several retrofit solutions have been simulated, by changing the following parameters:

1. Position of PCM layer: a) internal and external faces (indicated as "P_IE"), b) only external face ("P_E"), c) only internal face ("P_I"). The simulated configurations are shown in figure 2.
2. Melting temperature of the PCM, in the range 18-22 °C for PCM_H and in the range 26÷32 °C for PCM_C. The refurbished building will be named "T_n/m" where "n" is the value of the selected melting point (°C) for the heating period and "m" is the melting value assumed for the cooling season.

During the assumed cooling period, from the 23:00 in the evening to the 08:00 in the morning, natural night ventilation, achievable by simple openings of windows, it is fixed, with an airflow rate of 3 ACH. As underlined in [21], the night ventilation has a good effect on the process of charging/discharging (i.e., melting and solidification) of the phase change material. Night ventilation is an energy-saving strategy, by means of room ventilation during the night hours. This is important to allow cooling and recrystallization of the PCM, so that it can be able to absorb heat during a period of hot days. Seong et Lim have shown that the combination of both night ventilation and the PCM appears to be more efficient for cooling the building [ref.22]. Kendrick and Walliman have found that approximately 3 ACH is adequate, although higher ventilation rates may be required during warmer nights [ref 23.].

To evaluate the effect of night ventilation, it is only necessary to use an anemometer to measure the air velocity through window. For example, we can consider the calculation for the apartment on the second floor. Here there are eight windows (four closed during the night). The others are opened for about 10% of the total glassed area. So, the open windows' area is 1.5 m^2. The air flow rate is the area of the window multiplied by air velocity. If the air velocity is assumed at 1 m/s, the air flow rate is around 5'400 m^3/h. To calculate the achievable ACH, the flow rate has to be divided for the apartment volume (406 m^3), finally we have 13 ACHs. Diversely, if the air velocity is 0.3 m/s (so that no significant draft-risk occurs), there are 4.00 ACHs. In conclusion, it is possible an adequate natural ventilation.

Discussion and Results

The choice of the PCM for the maximization of the seasonal energy saving is a quite complex operation. This consideration, already inferred in [13] with reference to the cooling period, will be here confirmed. In particular, in the following sections, the presented study tries to suggest useful evaluations for designers and consultants, by means of a deepening about the real efficiency of PCM building materials. Indeed, at the present time, quantifications of annual savings aren't fully developed in the available scientific literature.

According to the proposed approach, the optimization of a refurbishment action - by means of phase change materials - should consider at least four aspects:

- annual primary energy saving;
- avoided polluting emissions;
- indoor comfort conditions;
- cost effectiveness.

These points will be in the next sections investigated for the presented case study. The authors consider this a useful starting point for further analyses on the evaluation of the PCM potentiality in the building sector.

Annual energy savings and avoided greenhouse emissions

In order to evaluate the effectiveness of PCM materials for the building technologies, two performance indicators have been used:

- the annual primary energy saving (ΔEP),

- the avoided emissions of equivalent carbon dioxide (ΔCO_2).

The LCA (Life Cycle Assessment) emission factor, considered for the combustion of natural gas, is the same in each countries and equal to 0.237 t $CO_{2\text{-}eq}$/MWh [24]. Diversely, the assumed emission factors for electricity are indicated in Table 6 and these differ among the EU States [24].

In the following study, it will be shown that all simulation results reveal that the application of two PCMs can induce a reduction of the building energy demands, both in the heating and cooling season and, for some conditions, the HVAC systems can be also turned off. This extreme situation occurs for Copenhagen and is referred to the summer cooling, where each simulated PCM nullifies the necessity of active cooling in the months of May and September. Consequently, the avoided emissions, only with reference to these two months, are 352 $kg_{CO2\text{-}equi}$. Moreover, several relevant considerations can be done about the obtained effects on varying of the position of the PCM layers and with reference to the considered melting temperature.

Table 6: LCA Emission factor for electricity consumption [22]

	Bordeaux	Copenhagen	Frankfurt Main	Naples	Stockholm
[$tCO_{2\text{-}eq}/MWh_{el}$]	0.146	0.760	0.706	0.708	0.079

With reference to Naples, Copenhagen, Bordeaux and Stockholm, the highest savings have been found with the application of the PCM plaster on internal and external faces, with reference to each combination of melting temperatures for the two considered PCMs. However, this configuration does not provide the same results in all months.
Figure 3 shows the primary energy saving for the different retrofit solutions in Bordeaux, when the melting temperatures are respectively 22 °C for PCM_H and 29 °C for PCM_C. The variations in primary energy demand are obviously referred to the comparison with the base building without PCM. During the heating season, 3 cm of PCM on both internal and external sides assure the highest energy saving (ΔE_H ≈ 748 kWh). No energy saving is achieved in March with P_I and P_E.
Diversely, during the cooling season, the wide temperature excursions of exterior wall surfaces cause a too fast melting of PCM_C and thus the better retrofit action consists in installation of a PCM on the inner face of external building envelope (ΔE_C ≈ 2064 kWh for P_IE and ΔE_C ≈ 2488 kWh for P_I). This result is consistent with [13]. The same analysis for the other melting temperatures and for the other cities (Naples, Copenhagen and Stockholm) provides similar outcomes.

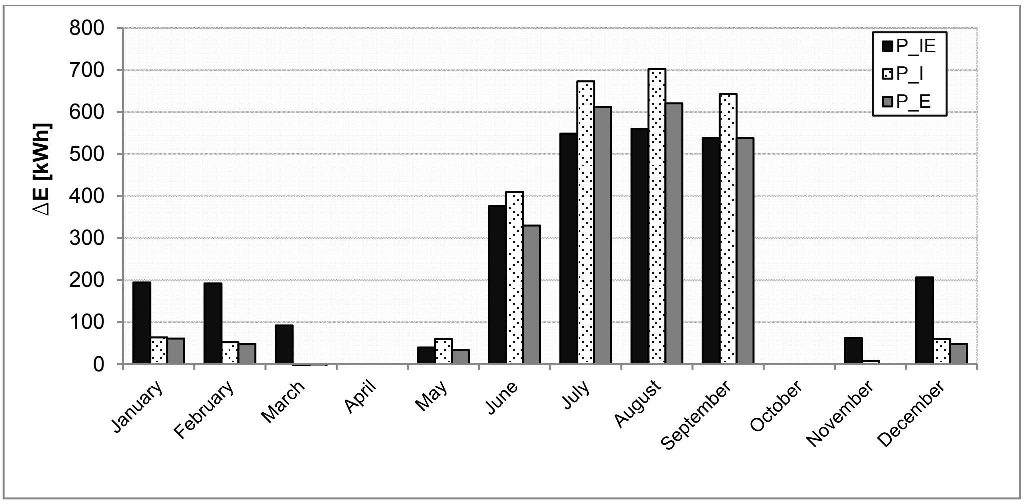

Figure 3: Bordeaux (France) - Effect of different configurations of PCM (T_22/29) on the annual energy demands

Furthermore, considering the climatic conditions of Frankfurt, the effect of different positions for the layers of PCM depends strictly by the melting temperatures, and then the best solution is not unique. Table 7 shows the main results, by varying both the position of PCM layers and the melting temperatures of PCM_C.

The installation of the two PCMs on the external facade with melting temperatures of 22°C (PCM_H) and 29°C (PCM_C) allows the highest primary energy savings during the cooling season and, being this reduction preponderant, also with reference to the entire year. Indeed, during the summer, several "forcing effects" affect the heat transfer from the outdoor ambient toward the indoor built environment, and thus the internal and external temperatures, the solar radiation, the long wave radiative heat transfer among building, sky and surroundings. Thus, both layers contribute to attenuate the amplitude of temperature fluctuations of the wall side exposed to the outdoor environment. In particular, the layer with the melting temperature of 22°C is activated during the first hours of the day, and it adds its effect to that of the second layer (29°C), that melts during the central hours of the day, at the peak of external load.

Table 7: Frankfurt am Main (Germany) - Seasonal and annual energy savings for different refurbishing actions

Action		Annual	Winter	Summer
Melting Temperatures	Position	ΔE [kWh]		
T_22/26	P_IE	1'870	138	1'732
	P_I	1'880	265	1'615
	P_E	1'709	294	1'415
T_22/29	P_IE	2'432	958	1'474
	P_I	1'892	269	1'623
	P_E	3'171	434	2'737

However, it is also evident that the highest saving, during the heating season, occurs when the PCM plasters are placed both on internal and external side of the wall. In this way, PCM_H is more frequently activated during the heating season and contributes to improve the indoor thermal comfort and to minimize the on-off cycles of the heating equipment. Instead, when the PCM is placed exclusively on the external side, it does not liquefy frequently, because the temperatures of the layer are too low.

Some interesting considerations can be done about the influence of different melting temperatures, with reference to all these retrofit solutions. In this regard and with reference to Naples, by considering the application of PCMs on both internal and external faces of the wall:

- In figure 4, the primary energy saving during the heating season is reported for various melting temperatures of the PCM_H plaster.
- In figure 5, the primary energy saving during the cooling season is reported for various melting temperatures of the PCM_C plaster.

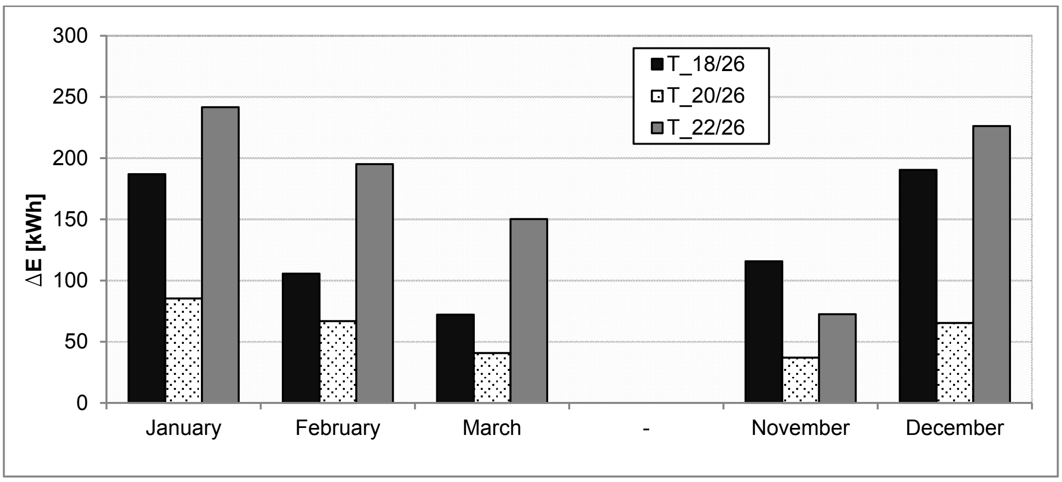

Figure 4: Naples (Italy) - Effect of PCM_H melting temperature on energy savings in heating demand

In Figure 4, it can be observed that a melting temperature equal to the indoor set-point temperature (20°C) allows the lower energy saving during the heating months (ΔE_H ≈ 295 kWh), while the better result occurs with a melting temperature slightly higher, around 22°C (ΔE_H ≈ 886 kWh). Good results are achieved also for PCM activated at a temperature of 18°C.
Moreover, also a higher melting temperature may be useful during the winter, because the radiative internal loads can raise the inner envelope temperatures, above all in the months characterized by not very cold outdoor temperatures.
On the other hand, the choice of a low melting temperature induces an under-utilization of the PCM in the coldest months. The same analysis for the other cities provides similar outcomes.
In figure 5 (also this referred to Naples), it's clear that during the summer, when the PCM_C plaster is placed on the external face of the envelope, the energy saving increases with melting temperatures higher than 26°C (i.e., set-point temperature during the cooling season). This result is in accordance with [13]. Frankfurt shows a similar trend, with an optimal melting temperature equal to 29°C.
In oceanic climate (Bordeaux and Copenhagen) and in Stockholm (humid continental climate), the cooling energy saving does not increase with the melting temperature if the PCM_C plaster is placed on the external side. Indeed, the summer average diurnal maximum temperatures are in the range 20 ÷ 27°C and the average diurnal minimum temperatures vary between 9 ÷ 15°C. Therefore, the PCM is fully able to exploit fully its storage potential with activation temperatures around 26°C.

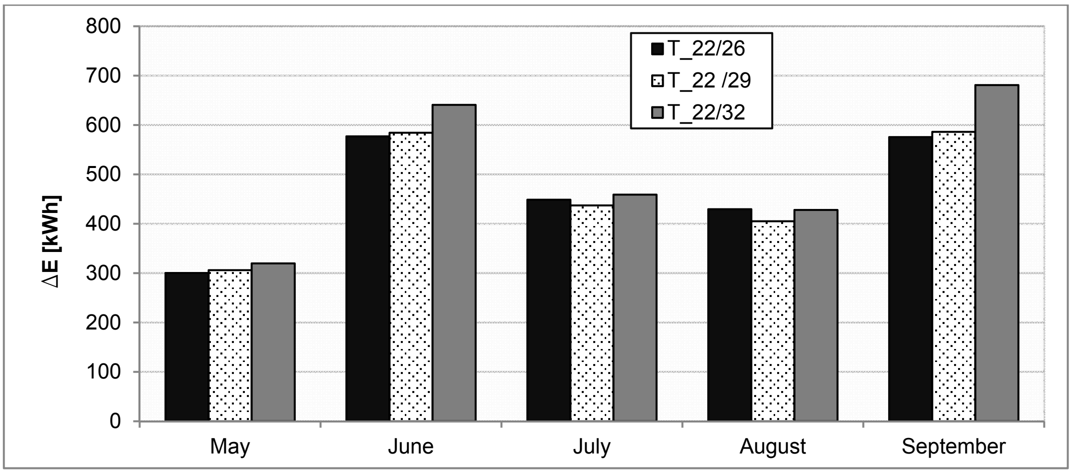

Figure 5: Naples (Italy) - Effect of PCM_C melting temperature on energy savings in cooling demand

Table 8: Energy and environmental analysis for the best refurbishing actions

Cities	Action		EP [kWh]	ΔE_{YEAR}	Annual	Winter	Summer	Annual	
	P_wall	Melting T [°C]		[kWh/a]	ΔE [%]			ΔCO_2 [kg]	ΔCO_2 [%]
Bordeaux	P_IE	T_22/26	45'517	2'816	5.8%	2.1%	17%	363	4.4%
Copenhagen	P_IE	T_22/26	69'777	1'968	2.7%	1.0%	34%	773	4.3%
Frankfurt Main	P_E	T_22/29	70'467	3'171	4.3%	1.0%	31%	900	3.6%
Naples	P_IE	T_22/32	50'709	3'225	6.0%	3.6%	7.9%	900	5.6%
Stockholm	P_IE	T_22/26	90'431	2'016	2.2%	1.0%	21%	300	1.6%

Table 8 shows the main energy and environmental results referred to the most proper refurbishment actions, with reference to all considered climates. Naples has the highest potentiality of reduction of energy demands and polluting emissions, because this city is characterized by the hottest climate and the PCM benefits are achieved mainly during the cooling season. About it, also with reference to the other investigated cities, the most significant outcomes concern the reduction of the energy requested for the space cooling.
If it is necessary the mechanical ventilation, according to technical data, we can assume that a typical mechanical ventilation system, for a conditioned floor area of 250 m^2, has a fan with a pressure head equal to 200 Pa. This implies, by assuming a fan efficiency equal to 0.7 and a volumetric flow rate of 0.21 m^3/s (it is the equivalent of 3 ACH necessary for discharging the PCM), an electric required

power of 540 W. This value has been multiplied by the number of operating hours (9 h) and the cooling period (120 days) and a primary energy demand equal to 140 $kWh_{PRIMARY}$ (it has been assumed an average efficiency of power plant equal to 0.46) has been calculated. The investigated building has a conditioned floor area around 690 m^2. Thus, three systems like the one before sized are necessary (conservative approach). It means around 420 $kWh_{PRIMARY}$/year. Finally, by comparing this value to the achievable energy savings (Table 8), it is perfectly reasonable.

However, it is important to underline that all results must be intended as trends, with the aim to suggest guidelines, suitable for orienting designer and professionals during the process of refurbishment. Indeed, these estimated saving potentials are the result of numerical evaluations and the measured performances could be slightly different, because of different assumed boundary conditions (e.g., climate, indoor set-points for temperature, thermal transmittance and inertia of the envelopes).

Effect of PCM on the indoor microclimate

This study evaluates the influence of PCM on the indoor microclimate. The adopted indicator is the Performance Index for temperature, a comfort index already used in [25, 26] and expressing the time percentage, for the heating (PI_H) or cooling periods (PI_C), characterized by indoor conditions within an established comfort range. With reference to common applications of civil sector, the following comfort ranges have been assumed:

- winter period: the indoor temperatures are comfortable if in the range 18 ÷ 22°C,
- summer period: the indoor temperatures are comfortable if in the range 24 ÷ 28°C.

The PI_H and PI_C, shown in figure 6, have been calculated for the refurbishing actions reported in Table 8, previously evaluated as the most suitable for achieving the highest energy savings.

Compared to the reference building without phase change plasters, figure 6 shows that PCM building allows a longer time percentage characterized by comfortable indoor conditions. This is verified for both the heating and cooling seasons.

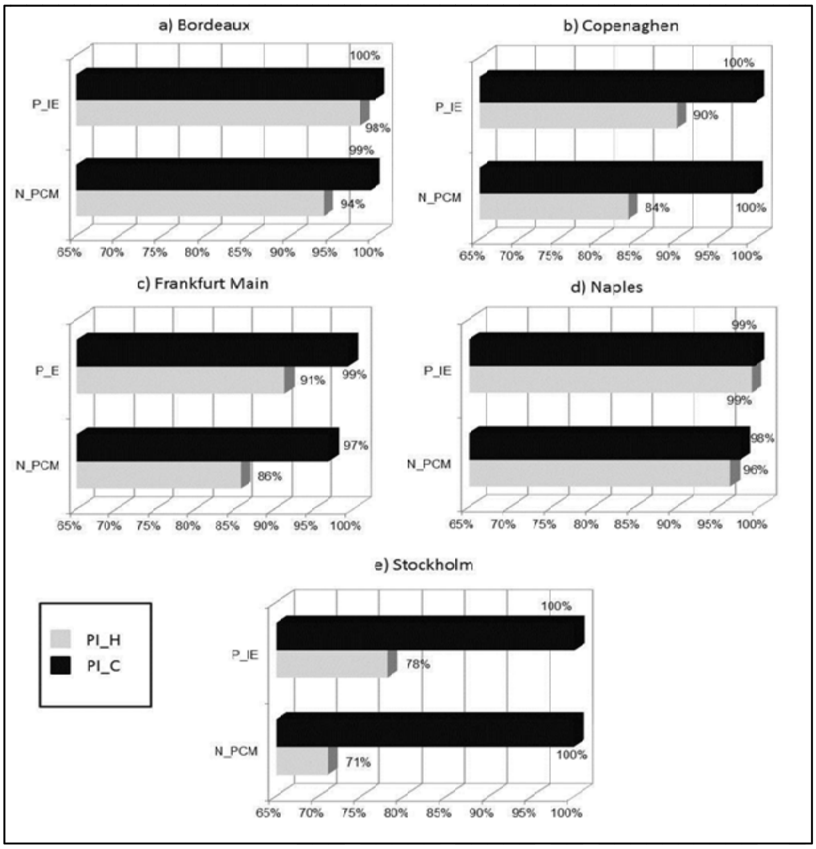

Figure 6: Performance Index of temperature referred to the most proper refurbishing actions

With reference to the summer season, for instance, the configuration with PCM plasters induces a lower inside surface temperature that implies a reduction of both operative temperature and cooling energy demand.

Some consideration about the economic aspect

Soares *et al*. have proposed a review about the economic impact due to the application of PCMs [4]. At the present time, only poor information are available about the PCM cost. Peippo *et al*. [27], in evaluating the effect of PCM wallboard for the climatic conditions in Helsinki, have assumed a cost of 1.5 $/kg for the PCM, and it leads to a payback time around 18 years. The same study shows that - in Boston - the payback period is in the range 3–5 years. Moreover in the library of materials available in the software Design Builder v3 [28], there are some BioPCM® phase change materials, with their costs. These are in the range 25÷35 pound sterling per square meter (GBP/m^2). In euro, it means around 30.0 - 42.5 €/m^2.
In this section, an economic analysis for Naples will be briefly carried out. Standard prices have been assumed for energy costs, derived from the Europe's Energy Portal, 2013, equal to 0.23 €/kWh_{el} for the electric energy and 0.90 and €/m^3 for the natural gas. Really, the energy costs differ all around the Europe. For reasons of brevity, these parameters have been fixed.
Starting by literature data and by including also labor and auxiliary operations, a cost of 45 €/m^2 has been assumed as installation cost of the PCM plaster. The overall investment has been evaluated around 40'700 €. The PCM plasters induce a reduction of the required annual primary energy of approximately 3'225 kWh/year, and it means an annual saving of 332 € in the operating cost. Finally, the achievable savings, at the present time, do not allow a payback period reasonable, being this much higher the usual 25-30 years considered as reference for energy efficiency measures applied in the retrofit of the building envelope. In the other climates, the feasibility study shows not satisfactory outcomes.
Surely, these aspects require a detailed analysis and cannot be properly analyzed in a general study like the one here proposed. Therefore, these initial economic considerations are aimed only to underline that the innovative peculiarity of this technology does not provide, today, an economic profitability. However, if the reference targets are energy efficiency and reduction of polluting emissions, the introduction of PCMs is a feasible operation.

In the future, the increased demand for energy-saving technologies and the consolidation of scientific results can contribute to the diffusion of this technology, so that a growing market of PCMs can also produce a reduction of the installation costs. About the future diffusion of PCMs, Reference [30] cites a Compound Annual Growth Rate around 20.1% between 2013 and 2018.

Conclusions

This paper investigates the effect of replacement of the internal and/or external plaster of all building vertical facades with two PCM plasters. These are characterized by different melting temperatures, so that one layer is active during the cold season (PCM_H) and the other one operates during the hot period (PCM_C). The building retrofit by means of PCM plasters is non-invasive and allows improvements of both indoor thermal conditions and energy demands, both in the heating and cooling seasons. The behavior of the case study building - used for retail (ground floor), warehouse (1^{st} floor) and dwellings (2^{th} floor) has been simulated with Energy Plus v.8.1.0, by adopting a solution algorithm based on the method of one-dimensional conduction finite differences.

The reduction of the heating and cooling energy demands, as well as the avoided polluting emissions, have been evaluated on varying of the phase change temperature and the location of the PCM layers. Some considerations are proposed also with reference to the cost feasibility.

Five climates have been considered, and thus Frankfurt, Naples, Copenhagen, Bordeaux and Stockholm. For the German city, the installation of two PCMs on the external side of the vertical wall, with melting temperatures of 22°C (PCM_H) and 29°C (PCM_C), allows the highest annual primary energy savings ($\Delta E \approx 4.3\%$) with 900 kg of avoided $CO_{2\text{-}eq}$ emissions. In the other climates, the highest savings have been found with the application of the PCM plaster on both internal and external faces of the walls, for each combination of melting temperatures of the two considered PCMs. However, the configuration does not provide the same results in all months.

The presented analysis confirms that the melting temperature should be reasonably chosen based on climatic conditions, because when the phase change enthalpy is fixed, this is the greatest influencing parameter. Generally, a melting temperature equal to indoor set-point temperature (20°C) allows the lower energy saving during the heating months. Diversely, the optimal winter melting temperature is 22°C for each climatic condition. During the summer, in hot Mediterranean climate (Naples), the cooling energy saving increases if the PCM_C plaster is placed on the external side of the wall and has a high melting temperature, around 32 °C. Instead, in oceanic (Bordeaux and Copenhagen) and humid-continental climates (Stockholm) a melting temperature of 26°C is more suitable.

Among all considered cities, Naples show highest potentialities of reduction of annual primary energy demand ($\Delta E \approx 6.0\%$) and polluting emissions ($\Delta CO_2 \approx 5.6\%$), with melting temperatures of 22 °C for PCM_H and 32 °C for PCM_C. During the cooling season, the greatest percentage saving is, obviously, achieved in cold climates (Copenhagen), where the cooling demand is reduced of about 34% in the summer months. In this case, the effect of PCM plasters nullifies the cooling loads during May and September.

About the indoor conditions of temperatures, these have been studied through the evaluation of the "comfortable hours" to "occupied hours" ratio. This indicator has been called Performance Index (PI) and has been calculated, for each city, by considering the best combination of PCM_S. In each climate, the performance index, for the building equipped with PCMs, is higher compared to the base building. During the heating period, the comfort hours pass from 71% to 78% of the occupied hours in Stockholm, from 86% to 91% of the occupied hours in Frankfurt am Main, from 84% to 90% of the occupied hours in Copenhagen. Moreover, Naples and Bordeaux have PI respectively equal to 99% and 96%.

During the cooling season, the Performance Index for temperature is 100% for Copenhagen and Bordeaux and 98% for Naples and Frankfurt.

All told, even if only some outcomes of the global study have been reported, the paper tried to suggest guidelines for both design and optimization of PCM installations, with reference to common European buildings. Next studies will provide closer examination, by comparing simulative investigations to experimental studies, that will be carried out at the Matrix Lab. The test cell, a full-scale experimental facility, at the present time is under procedure of assignment/installation at the University of Sannio in Benevento.

Nomenclature

C_p	Specific heat	[J/kg K]
EER	Energy Efficiency Ratio of Chiller	$[W_{THERMAL}/W_{ELECTRIC}]$
EP	Primary energy demand for the space air-conditioning	[kWh]
h	Specific enthalpy	[kJ/kg]
k	Thermal conductivity	[W/m K]
PI	Performance index	[%]
S/V	Dispersing surface to conditioned volume ratio	$[m^{-1}]$
t	Time	[h]
T	Temperature	[°C]
U	Thermal transmittance value	$[W/m^2K]$
x	Thickness	[m]

Greek letters

Δ	Difference	
ρ	Density	$[kg/m^3]$

Subscripts

C	Cooling season
f	Melting/fusion value
H	Heating season
i	Modeled node
i+1	adjacent node to interior of construction
i-1	adjacent node to exterior of construction
j	Current time step
j+1	new time step
w	interface between i and i+1 node

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Energy-oriented refurbishment of a Railway Station in Mediterranean climates: a case study of cost optimal analysis

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Abstract

In the frame of recent European and Italian legislations in matter of energy efficiency of buildings, the paper, starting from a real case study - a Railway Station of an Italian southern city (Benevento) -, proposes a large energy-oriented refurbishment of all systems connected to the energy efficiency. More in detail, the refurbishment concerned the building envelope, the active installed HVAC system, the integration of energy demands by in-situ renewable energy sources.
By considering the Mediterranean peculiarities, the study is focused on the effectiveness of various solutions aimed at reducing the energy demand in both the heating and cooling seasons. In particular, beyond the design of a new air-conditioning system, for improving the indoor comfort conditions and air-quality, a set of energy efficiency measures has been applied. Opaque envelope insulation, new windows, solar screens, green roofs, heat recovery and high-efficient heat generation system, by considering location and destination of use (i.e., high internal loads connected to the large transparencies, intensity of office equipment and plugged devices, warm climate of the South Italy) are evaluated in order to reduce the present energy requests. All studies have been carried out by means of hourly energy simulations, after a proper calibration of the input data. Each energy efficiency measure has been singularly analyzed and then the most feasible ones have been combined. Furthermore, also a photovoltaic system is proposed. The outcomes reveal that the present building energy demand and energy related pollution could be strongly decremented, by means of a "cost-optimal procedure", in order to optimize the investment in energy retrofit.

Key Words

Green roofs; Railway Station; Building energy efficiency; Cooling demand.

Introduction

According to future targets of pollution reduction and in order to rationalize the energy use in the EU countries, in the last years several documents have been enacted by the EU Institutions, among which the Directive 2010/31/EC "Directive of the European Parliament and of the Council of 19 may 2010 on the energy performance of buildings" [1]. In particular, the article 9 (paragraph 1), established - by 31 December 2020 - that all new buildings should demand nearly zero-energy. A demonstrative role is attributed to buildings occupied and/or owned by public authorities, and the date of nearly zero energy buildings is anticipated, for these, at January 2018.
At the same time, each energy efficiency program that does not take into account the existing building stock cannot obtain significant impacts on the present energy request and pollution related to its uses, because of - as well-known - the quite low turn-over rate of buildings all around EU countries.
In this regard, it is quite explicit the Directive 2012/27/EU [2] that, at the art. 4 established, for EU Member States, "a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private".
The cited Directive strongly promotes:

- the "cost-effective approaches to renovations, relevant to the building type and climatic zone",
- "policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations",
- "forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions",

- "an evidence-based estimate of expected energy savings and wider benefits".

An entire article, the number 5, is dedicated to the "Exemplary role of public bodies' buildings". In particular, "each Member State shall ensure that, as from 1 January 2014, 3 % of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet at least the minimum energy performance requirements".

Within this frame, the Italian policies - in the last years - already largely supported the energy efficiency in the buildings' sector. Indeed, energy laws have been enacted - at the same time - for imposing new energy efficiency targets for new buildings and refurbished ones and - on the other hand - in order to support the energy efficiency when not mandatory.

For instance, starting by the Decrees of February 2007 [3, 4, 5], the following energy efficiency measures (EEM, in the following of the paper) have been funded:

- energy refurbishment of private buildings (i.e., new thermal insulation, new energy-effective windows, condensing boilers, high-efficient heat pumps, solar system for hot water productions, heat pump water boilers), by means of high tax-deduction incentives (firstly equal to the 55% of the total cost of the EEM, today at 65% [6]);
- installation of renewable energy sources for the electricity conversion, by means of the "net-metering" and "feed-in-tariffs" tools.

The above-cited legal acts have been constantly upgraded, together with the investment cost variation. For instance, the feed-in-tariff mechanisms have been progressively reduced with the decreasing of the installation cost of photovoltaic technologies.

In the last years, also public buildings have been admitted to public incentives for promoting energy renovations. This is the case of the Decree of 28 December 2012 [7] titled "Incentives for the production of thermal energy from renewable sources and measures for small interventions of energy efficiency". This Italian legislative measure - called "Thermal Account" in technical jargon, is framed into the Italian measures for reaching the European targets in matter of energy efficiency and renewable integration established for the 2020. This law funds both production of thermal energy from renewable sources, such as biomasses, solar systems and efficient heat pumps, but also the strategies for the energy "conservation" in buildings, and thus insulation of the envelopes, low-U windows, efficient control systems for the heating management.

Moreover, other important programs are presently at the conclusive phase, such as the Interregional Operational Program (POI) [8], approved in 2007 by the European Commission and to be completed by 2013, aimed to increase energy consumption produced by renewable sources and to promote local development opportunities by enhancing energy efficiency. The program - specifically for public administrations, local authorities, but also private individuals - has been subdivided into three main areas of intervention:

- Priority I - Production of energy from renewable sources.
- Priority II - Energy efficiency and optimization of the energy system.
- Priority III - Technical assistance and accompanying actions.

With this program, energy efficiency actions and renewable installations in some Italian regions, i.e., the so-called convergence Regions (Calabria, Campania, Puglia and Sicilia), have been funded for more than over 1 billion of Euros, with a share around 75% funded by the European Institutions, and in particular by the European Regional Development Fund (ERDF [9]). This is a dedicated economic tool allocated at the European Union.

In this cornice, that reveals a great present interest in matter of energy efficiency of existing buildings, with reference to both conservation of energy and installation of systems and equipment for energy efficiency, in the following sections the case study of Appia Railway Station in Benevento is presented. Immediately, it is necessary to specify that this is a simple investigative study, in order to evaluate margins of achievable energy savings, by improving firstly the HVAC system and then the building envelope. Furthermore, a last study investigates the technical feasibility of a plant for the in-situ electricity conversion from renewable sources.

Appia Railway Station: history

The case study building is a railway station of Benevento, a middle-size city of Southern Italy, located in the Campania Region. The "Appia Station" is placed along the ancient Via Appia, one of the consular roads built under the Roman Age, for connecting Rome to Brindisi, a city of the southeast Italy, that faces on the Adriatic Sea. Road and Station take the name from Appius Claudius Caecus, that, during the IV century before Christ, promoted the construction of Via Appia for military

and strategic scopes.
With reference to the Railway Station, this is not the main one of Benevento. However, it has a strategic role, still today, because probably is the closest to the city center, and thus is highly frequented by people that should reach the town. Presently, Benevento has an important University (i.e., University of Sannio) with many students, employers and teachers coming - by train - from Naples and from the entire Province of Benevento.
Beyond the rail dedicated to the travelers' transport, other tracks are used for services. Indeed, the Station has a large hangar for the train maintenance and repair.

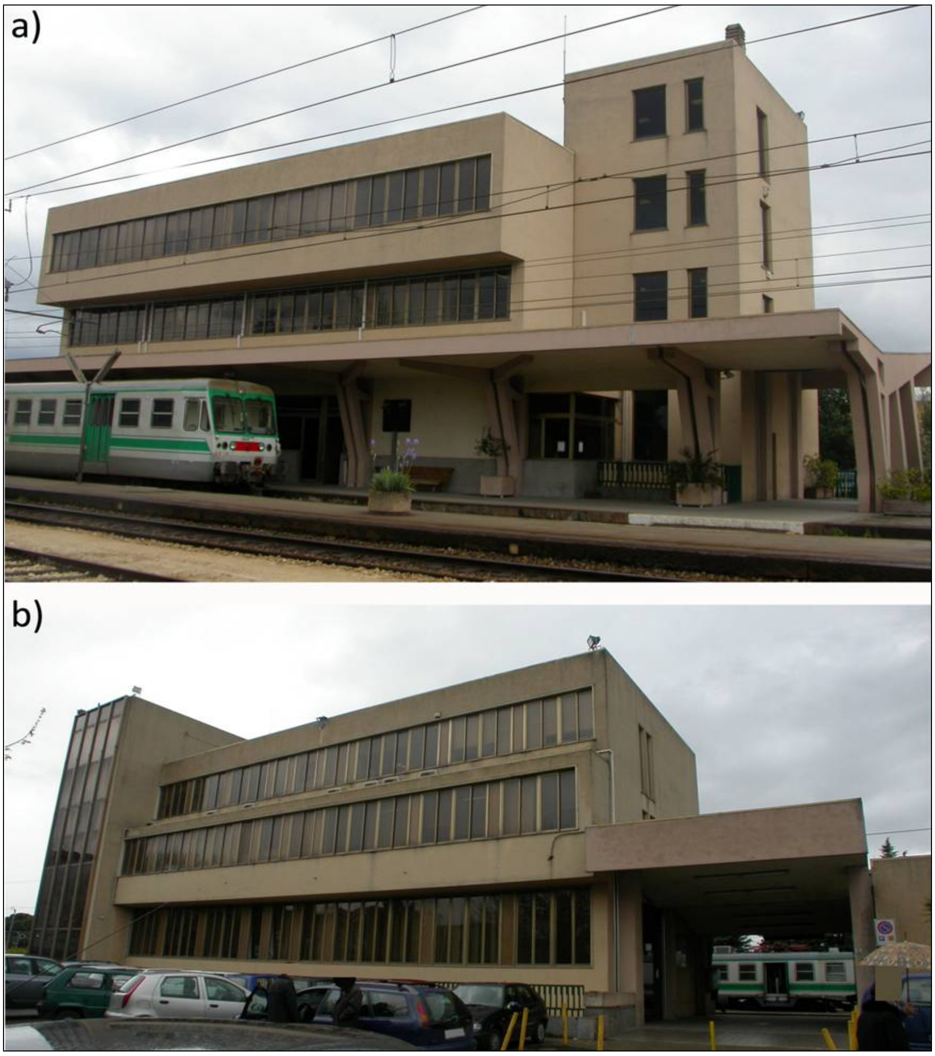

Figure 1 - The present aspect of Appia Railway Station, from two points of views: a) from the tracks, b) from the parking area

The present building, shown in Figure 1, has been built in the 1987 [10], because the original architecture was largely damaged by the earthquake of 1980. About it, the cited earthquake caused great damages and destructions in the entire Campania Region, above all in the province of the near city of Avellino.
At the construction period, the Italian Legislation about the building energy efficiency was not completely developed. At that time, all prescriptions were established by the Law 373/1976 [11] that, in the years after the Kippur war, tried to set minimum requirements of energy efficiency in order to reduce the energy demands also with reference to the building sector.
However, this law had a low impact on the energy efficiency of the Italian building stock, so that, some years later, the L. 10/91 [12] was enacted in order to harmonize the legislative frame, above all by considering the energy efficiency of the HVAC systems beyond the efficiency requirements established for the building envelopes.

The case study of Appia Railway Station

In this section, the thermal-physical property of the present envelope of the Appia Railway Station, as well as the description of the heating and cooling system, will be provided. Presently, the Appia Station has two main buildings, connected by means of a passage necessary for reaching the tracks from the parking area. The main building, shown in Figure 1, has three storey's above the ground and one partly buried. The second building, mainly used for additional office, consists in a single storey architecture. The construction technology is typical of the Italian building tradition of the second half of the XIX century, and thus a structural frame in reinforced concrete and hollow clay blocks.
The overall floor area is 1332 m^2, and it includes, at the ground floor, a newsstand, a cafeteria with tobacconist, the ticket office, the waiting room and technical office for the train service control. The second and third floors are used as office, as well as the second adjacent building. The envelope structures are shown in figure 2.

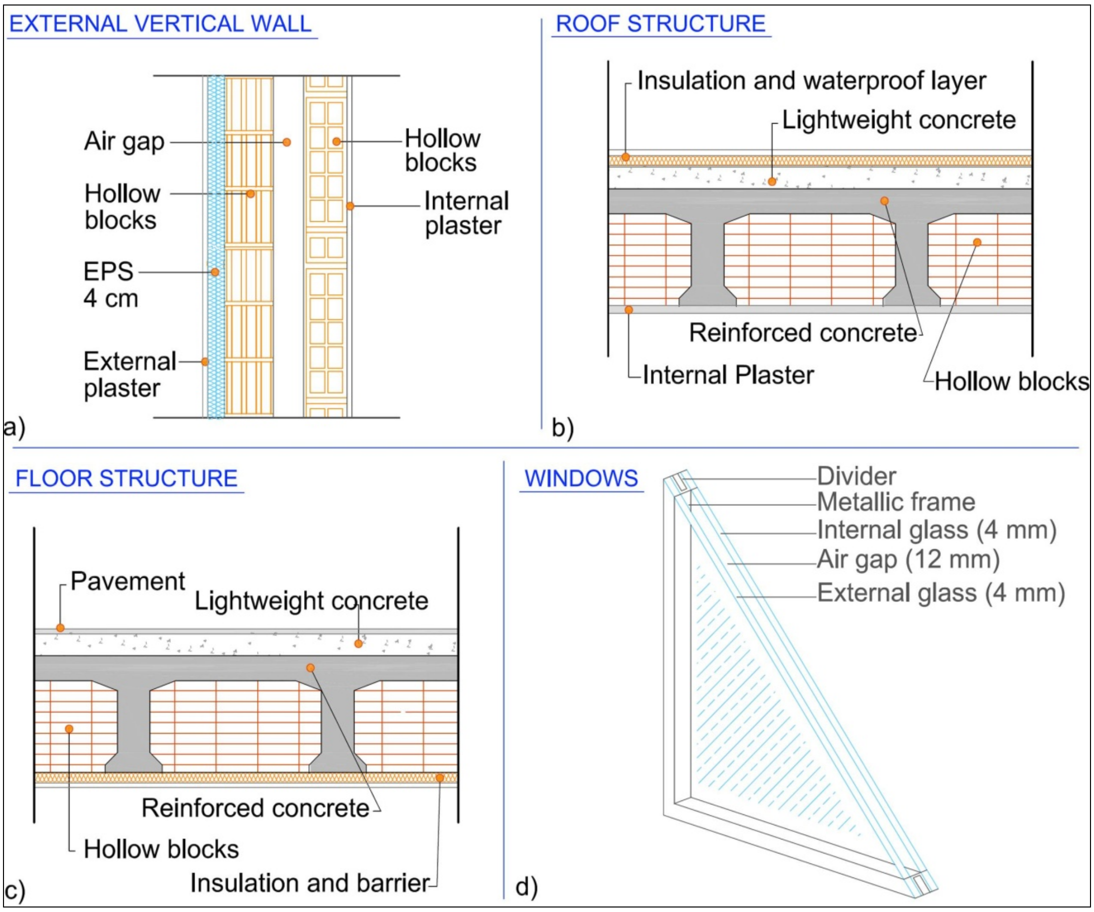

Figure 2 - The envelope structures of the Appia Railway Station

The building structures are described in the following bulleted list:

- The external walls of the envelope have a composite structure, with vertical cladding made in hollow blocks (two layers with an interposed air cavity), with external insulation (4 cm of polystyrene), plastered on both the sides. The overall U_{value} is 0.48 W/m^{2}K.
- The horizontal structures - and thus ceiling, basement and floors - have concrete joists with interposed hollow blocks and an upper layer in reinforced concrete. The overall U_{values} are 0.742 W/m^{2}K for the floor on the ground and 0.75 W/m^{2}K for the roof structure.
- The windows have a PVC frame, without thermal breaks, with a double layer of glass and an air gap air-filled (4/12/4). The overall U_W (i.e., the average weighted value by taking into account glazed part and frame) is around 2.72 W/m^{2}K, with a SHGC equal to 0.76.

The building thermography, reported in Figure 3 (January 2014), revealed significant air-infiltrations from windows, absence of relevant thermal bridges, weakness of the large glazed area of the stair block. All main characteristics of the building envelope are reported in Table 1.

With reference to the heating and cooling systems, the Appia Railway Station recently replaced the centralized system (hot water generator and in-room radiators), with autonomous devices based on the direct expansion technology, installed in each room. Staircase and common spaces (i.e., corridors, passages) are not air-conditioned. The same packaged air-conditioners allow also the summer cooling. In both the seasons, the air changes are based on natural ventilation, by means of the windows and doors' openings.
All told, the present "ready-to-use" equipment for air-conditioning cannot properly allow an adequate microclimatic everywhere inside the building, without properly controlling the hygrometric conditions neither the air quality.

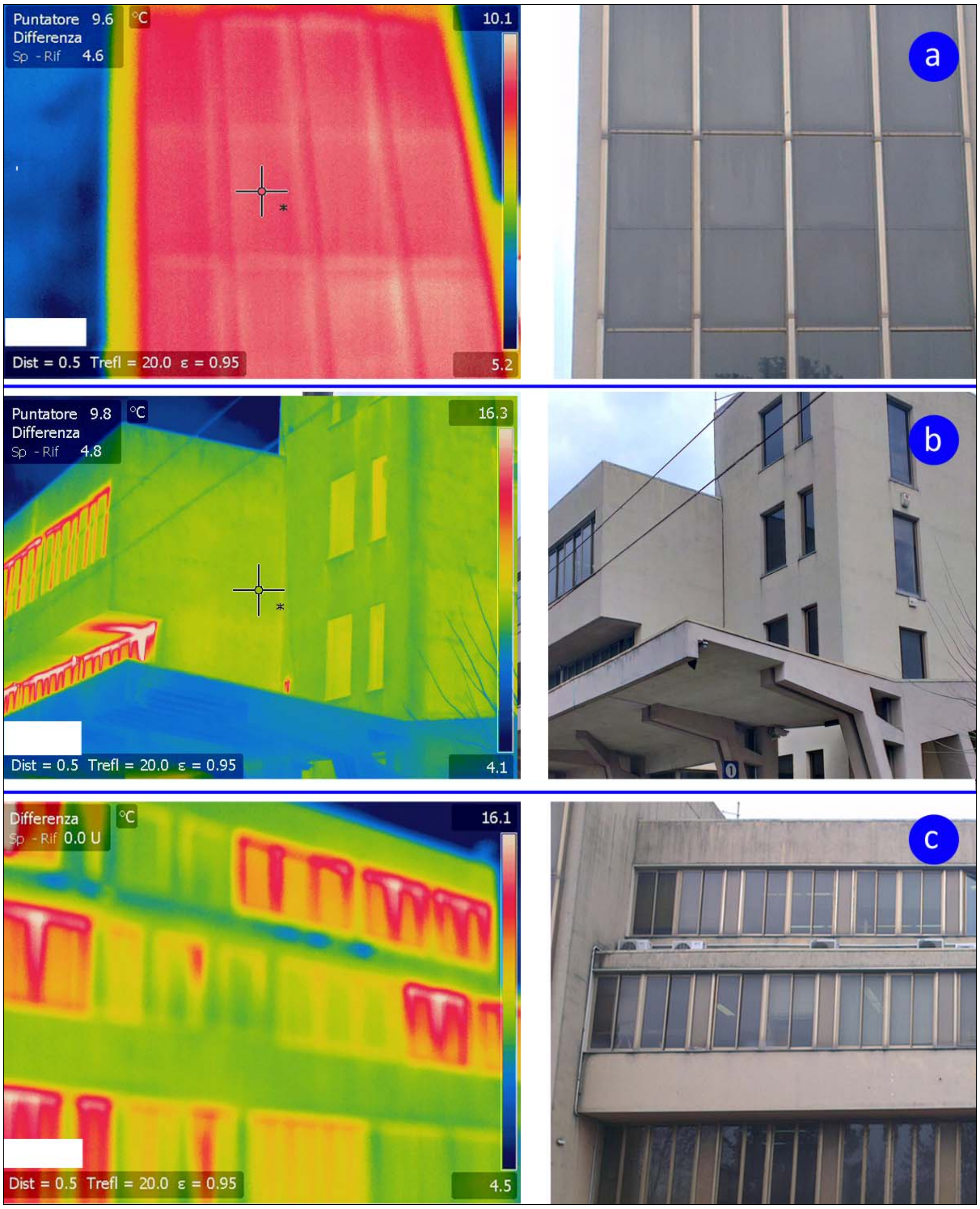

Figure 3 - Thermography of the building: a) Staircase, b) Point of view from tracks, c) Main facade

Table 1 – Building characteristics

MAIN BUILDINGS' DIMENSIONS AND GEOMETRY					
Total building Area	1332 m^2	Length (N-S direction)	56.3 m	Gross Volume	4775 m^3
Maximum Height	15.00 m	Length (N-S direction)	12.0 m	Surface to Volume Ratio	0.546 m^{-1}
BUILDING ENVELOPE					
$U_{EXTERIOR\ WALLS}$	0.48 W/m^2K	$U_{UPPER\ ROOF}$	0.74 W/m^2K	Windows SHGC	0.76
$U_{GROUND\ FLOOR}$	0.75 W/m^2K	$U_{WINDOWS}$	2.72 W/m^2K (5.5 W/m^2K for the stairs)	Infiltration flow Rate	0.75 ACH
HEAT TRANSFER AREA OF EXTERNAL WALLS, ROOF AND FENESTRATION FOR THE EXAMINED BUILDING					
	Total	North *from 315° to 45°*	East *from 45° to 135°*	South *from 135° to 225°*	West *from 225° to 315°*
Gross area of vertical walls	1620.9 m^2	263.7 m^2	546.7 m^2	263.7 m^2	546.8 m^2
Window opening area	347.4 m^2	7.75 m^2	197.3 m^2	8.82 m^2	133.5 m^2
Window-to-wall ratio	21.4 %	2.94 %	36.1%	3.3 %	24.4 %
Gross roof area [m^2]	492.7 m^2				

Refurbishment of the HVAC system

A deep renovation of the present systems for the air-conditioning is recommended in order to allow a suitable microclimatic control. In this regard, in this study, the building has been analyzed under the point of view of the hosted functions, in order to design a proper HVAC system, above all with reference to the necessary indoor air quality, and thus by sizing properly the mass flow rate to supply into the zones.

The designed HVAC plant is a mixed air-water system. The fan-coils guarantee the temperature control (by balancing the sensible heat loads), and the primary air - managed by an air handling unit (AHU) - allows the necessary air changes and the control of the latent loads.

In the design of renovation of the HVAC system, the entire building has been divided into 46 thermal zones, each of these characterized by one of the following uses: waiting room, bathrooms, horizontal corridors an passages, stairs, bars, offices, ticket office, stores, and technical spaces.

Table 2 – Characteristics of the new HVAC system

Mixed air/water System, with fan coils and Dedicated Outdoor Air Handling Unit	
HVAC Typology	Mixed air/water System, with fan coils and Dedicated Outdoor Air Handling Unit
Ventilation Air	Ranging from 0.5 ACH (stairs) to 2.7 ACH (cafeteria and bathrooms)
Sensible Load control	Yes, for single zone
Latent Load Control	Yes, for single zone
AHU Cooling coil: Chilled Water Coil	Rated Sensible Capacity - 50 kW, Rated Latent Capacity - 25.8 kW
AHU Heating coil (Hot Water Coil)	Capacity = 49.2 kW
AHU Fan parameters (efficiency: 0.7)	Delta pressure = 500 Pa, Air Flow = 2.75 m^3/s
Pumps (motor efficiency: 0.9)	Rated power: Hot water loop: 1100 W, Chilled water loop: 1820 W
AHU Electric Humidifier	Electric power: 10.8 kW, Humidification capacity: 7.5 * 10^{-3} m^3_{water}/s
Fan-coil: Four pipe fan-coils, equipped with two coils	- Cumulative Chilled Water Flow Rate: 0.0031 m^3/s - Cumulative Hot Water Flow Rate: 0.0037 m^3/s - Cumulative Maximum Air flow rate: 5.6 m^3/s (i.e., recirculation air)
Boiler (traditional type, high efficient)	Nominal Capacity: 188.5 kW, Nominal η: 0.945
Chiller (Air cooled, scroll compressor)	Nominal Capacity: 199.4 kW, Nominal EER 3.1 $Wh_{THERMAL}/Wh_{ELECTRIC}$

The combining of a Dedicated Outdoor Air System and in-room fan coils has been designed for providing, in both the seasons of heating and cooling, a full microclimatic control, for permitting suitable indoor comfort conditions in terms of temperature, relative humidity and air-quality.

With reference to the air changes rate, these have been sized by considering the indications of the EN 15251 [13], and thus by establishing a fixed quote (based on the surface area) and an adjunctive amount of outdoor air calculated with respect to the zone occupancy rates.
Finally, a dedicated outdoor air system designed for the latent control (i.e., set point of relative humidity equal to 50% in both the heating and cooling seasons, during the occupied hours) is combined to a hydronic system for the sensible load control. The systems are turned on during the office hours - and thus from 8.00 in the morning to 18.00 in the evening.
It is important to underline that the indoor microclimate is controlled for seven days/week only in some zones, such as waiting rooms, bars, and cafeteria, while the offices and - more in general - all the spaces at the upper floors have been designed as air-conditioned for five days/week.
The main characteristics of the new HVAC system are reported in Table 2. The investment cost, according to Italian common prices, can be estimated around 195'000 €. The HVAC cost has been evaluated according to the typical Italian market, considering a mixed air/water system (primary air and fan-coil units). This is provided, according to [14], with high-efficient hot water boiler and air-cooled chiller. The expenditure for the HVAC system has been considered necessary, in order to allow a comfortable use of the building. Therefore, this base cost will not be considered in the next optimization study.

Definition of suitable numerical model and evaluation of the energy performances of the present building

The aim of this study was the energy refurbishment of the present building, with reference to both the envelope and the heating/cooling systems. Building Energy Performance Simulations (BEPS) have been carried out by the use of EnergyPlus 7.2.0 [15]. All available data, referred to the building, have been used for the model definition, and thus the building use, the thermal-physical characteristics of the envelope such as above described, occupancy, load profiles and use of the HVAC. According to the International Standard EN 15603 [16], an energy audit can be carried out according to three alternative methodologies, i.e. “asset”, “design” or “tailored” ratings. The first two investigation modalities are based on semi-steady state simulations, by assuming average values of the internal and external microclimatic conditions and conventional values for the modeling of various boundary conditions. In this paper, diversely, a deep study, specified for feasible renovations, has been carried out, and thus a "tailored approach" has been adopted, through hourly energy simulation and boundary conditions as reliable as possible.

As said, the Appia Railway Station has been modeled in EnergyPlus, one of the most authoritative programs for the whole building energy analysis [17, 18]. Indeed, the goal was a reliable simulation of a building, in order to verify the profitability of energy efficiency measures, in terms of technical and economical convenience, as well as in order to reduce the present energy demands and the connected environmental emissions. Therefore, each boundary condition for the simulations has been properly defined. Within this aim, also a specific hourly weather file for Benevento has been developed, being this not available in the IWEC database. Only for the geometrical definition of the building, the program DesignBuilder [19] has been used, while the HVAC system has been directly modeled in EnergyPlus.

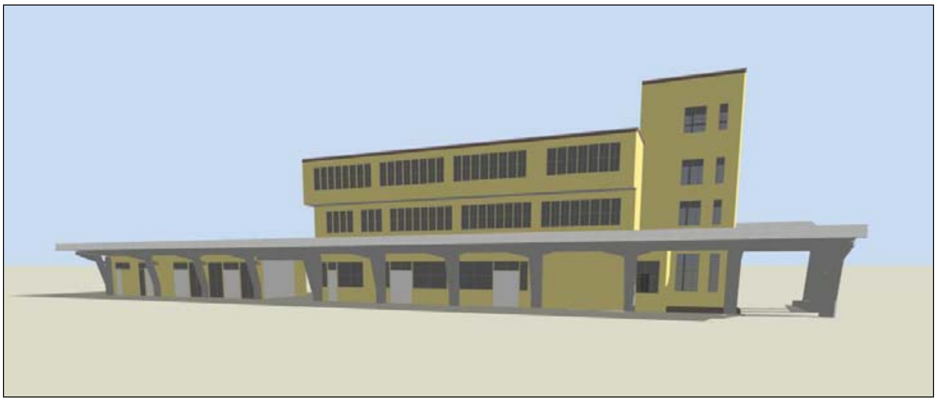

Figure 4 - The building model in DesignBuilder [19]

Once created the model of building and HVAC system, the following general simulation criteria have been adopted in EnergyPlus:

- Heat Balance Algorithm: Conduction Transfer Functions.
- Timestep per hour: 2.
- Surface Convection Algorithm Inside: variable natural convection based on temperature differences.
- Surface Convection Algorithm Inside: correlation from measurements for rough surfaces.
- Maximum HVAC iterations: 20.

With reference to the data elaboration, the following parameters, costs and coefficients of emissions have been considered:

- Efficiency of Italian power generation system: 0.46 $kWh_{ELECTRIC}/kWh_{PRIMARY}$.
- Lower calorific value of the Natural Gas: 9.59 kWh/m^3.
- LCA emission factor for Natural Gas: 0.237 ton CO_2/MWh [20].
- LCA emission factor for electric energy: 0.708 ton CO_2/MWh [20].
- Electricty cost: 0.229 €/kWh [21].
- Natural Gas cost: 0.083 €/kWh [21].

The annual energy demand for the space heating, calculated for a unitary floor area (in the following rows defined EP_i) is equal to 72.6 kWh/m^2a. In summer time, in order to provide the building cooling and the necessary dehumidification, the building requires around 44.6 kWh/m^2a.

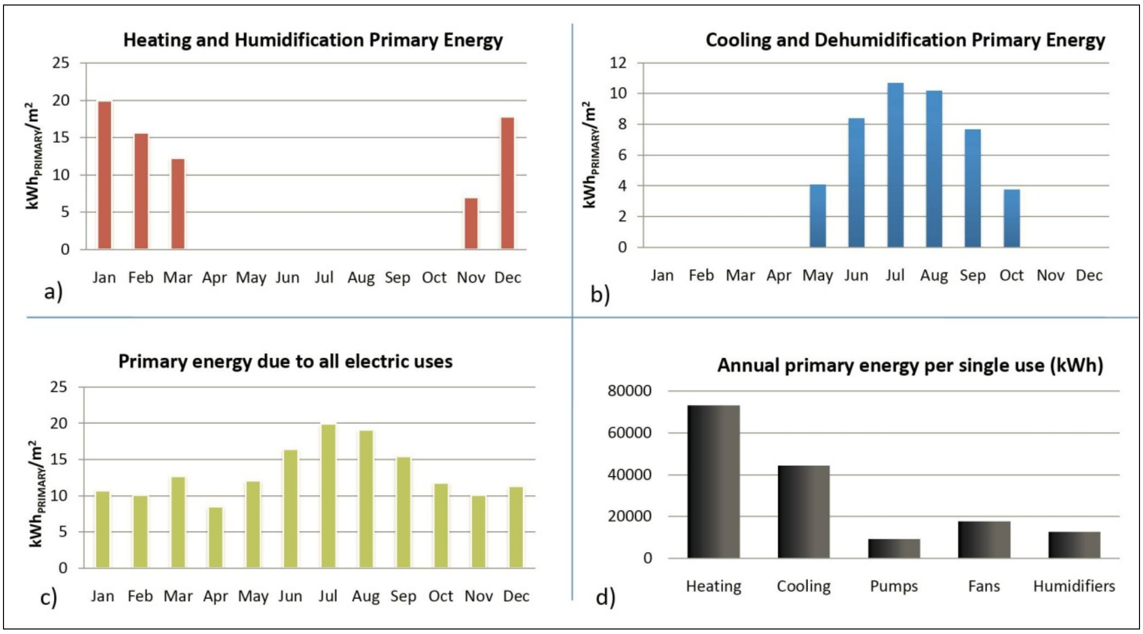

Figure 5 - Energy demands of the base building as simulated

Table 3 - Thermal loads and energy requests for A/C of the present building equipped with a new HVAC system

	Mixed Air / Water system	Unit
Heating	72'991	$kWh_{PRIMARY}$
Cooling	44'220	$kWh_{PRIMARY}$
Fans	17'518	$kWh_{PRIMARY}$
Pumps	9'142	$kWh_{PRIMARY}$
Humidification	12'511	$kWh_{PRIMARY}$
Total	156'381	$kWh_{PRIMARY}$
Total	118.4	$kWh_{PRIMARY}/m^2$

The above-reported energy demands imply an annual cost equal to 14'698 €, due to an expenditure for the winter heating around 8'483 € and equal to 6'212 € in summer time. With reference to the environmental impact of the present building, the following emissions of equivalent CO_2 have been calculated, for the space heating/humidification (24.8 tons $CO_{2\text{-equiv}}$), space cooling/dehumidification (19.2 tons $CO_{2\text{-equiv}}$), and annual air-conditioning (44.0 tons of $CO_{2\text{-equiv}}$). All main energy indexes are reported in Table 3. Obviously, the histograms of figure 5a and 5b include the energy demands for fans and pumps.

Starting from the above-presented energy demands and polluting emissions - quite high according to the present standards in matter of energy efficiency in buildings -, in the next section the building envelope will be renovated, and also some suitable energy efficiency measures applied at the HVAC configuration will be discussed. The aim of the study is the proposition of a cost-effective refurbishment for improving the overall energy performances, and thus by reducing the operating costs as well as the pollution related to the building use.

Feasibility study about suitability of common Energy Efficiency Measures

The Southern Italian climate is quite favorable, and thus the aforementioned energy demands are quite high if compared to the external ambient conditions and to the building use (mainly, 5 days/week and 10 hours/day). Therefore, in order to improve the use of energy, a set of EEMs has been tested, by singularly considering:

A. Replacement of windows, by adoption of low-emissive glass with a reflective coating. The present glazed surface has an overall U_{value} equal to 2.7 W/m^{2}K. The new proposed systems are characterized by a U_{value} of 1.6 W/m^{2}K, with a SHGC factor of 0.704. The systems include wooden/aluminum frames and external shading systems with high-reflective slats. These are automatically activated according to the incident solar radiation (> 120 W/m^2).
B. Installation of new windows - identical to those described at the point A - only for the staircase block (where, presently, there is a single-glass). The new windows are equipped with reflective shading rolls, movable – when necessary – by means of manual variation.
C. Improvement of the building airtight (see figures 3b and 3c), by replacing only the old and damaged seals of windows. Presently, the estimated air infiltration is around 0.75 ACH. The replacement of seals and the overhauling of frames is assumed as a proper action for reducing this value at 0.25 ACH.
D. Additional thermal insulation of the vertical opaque envelope, by adding further 6.0 cm of extruded polystyrene in flat panels. The present wall transmittance, equal to 0.48 W/m^{2}K, is reduced at 0.28 W/m^{2}K (-42%).
E. Additional insulation, by means of further 8.0 cm of extruded polystyrene, of the roof structure. The present slab transmittance, evaluated equal to 0.74 W/m^{2}K, is reduced at 0.30 W/m^{2}K (-60%).
F. Adoption of a green roof in order to reduce both the building demands for heating and cooling. This new roofing technology consists in an extensive greenery: C3 vegetation, with medium height (25 cm), medium Leaf Area Index (2.0 m^2/m^2), medium stomatal resistance (200 s/m), leaf reflectivity equal to 0.4. The green roof includes the soil layer, an underlying insulation and the irrigation devices.
G. Installation of a condensing hot water boiler instead of the traditional one, high efficient, presently designed. In order to provide hot water to the heating coil of the air handling unit and to the fan-coils, a condensing hot water boiler (rated efficiency 0.99) is quite suitable, because low temperatures are required for the supply warm water.
H. Adoption of an heat recovery system - both sensible and latent - in order to improve the performance of the Dedicated Outdoor Air System. An enthalpy heat exchanger is installed in the Air Handling Unit, in order to reduce the ventilation loads by recovering energy from the exhaust air. The efficiencies, at rated conditions, are below defined: rated sensible effectiveness equal to 0.75, rated latent effectiveness equal to 0.70.

The studies will be performed according to installation costs typical for the Italian market. For some EEMs, such as the building insulation and the windows' replacement, according to the Italian law, a public incentive can be obtained [7]. Thus, in the calculation of economic indicators of profitability, this funding will be taken into account. For the HVAC system, incentives have been not considered, because this has been considered as new installation (being, the present one, quite different, so that this is not a mere "replacement"). All installation costs, as reported in Table 4 (that infers also the various results of energy simulations), consider the entire investments necessary for the energy efficiency measures, and thus also security charges, scaffoldings, temporary works in the construction site.

Starting by the potential benefits derivable by the single actions before cited, the final goal is a global energy refurbishment. Therefore, each individual EEM has been singularly simulated. Then, the more profitable ones have been combined. A deep investigation by means of hourly energy simulations has been carried out for each one of the above-presented energy efficiency measures, with energy studies carried out for the entire year in order to understand also eventual adverse effects, as, for instance, eventual hyper-insulation phenomena in summer time.

Table 4 – Summarized feasibility analysis of considered EEMs

EEM	ΔEP		Δ Operating Cost		Δ $CO_{2\text{-equiv}}$ emissions		EEM Cost	DPB
	(kWh/m^{2}year)	(%)	(€/year)	(%)	t $CO_{2\text{-equiv}}$/year	(%)	(€)	(years)
A*	25'580	- 16.5	2202	- 15.0	6.37	- 14.5	234'495	> 40
B*	7'512	- 4.8	664	- 4.5	1.94	- 4.4	27'770	> 40
C	17'223	- 11.1	1'438	- 9.8	4.12	- 9.4	13'896	> 11.5
D*	2'857	- 1.8	233	- 1.6	0.66	- 1.5	66'220	> 40
E*	4'223	- 2.7	359	- 2.4	1.03	- 2.4	26'129	> 40
F*	4'985	- 3.2	** 421	- 2.9	1.21	- 2.8	55'216	> 40
G***	15'355	- 9.9	1'191	- 8.1	3.31	- 7.5	4'985	> 4.5
H	15'798	- 10.2	1'389	- 9.5	4.05	- 9.2	11'500	> 9.6

** This energy efficiency measure can benefit, according to [7] of a funding equal to 40% of the installation cost. This will be guaranteed in five yearly tranches of equal value.*
*** This outcome does not consider the artificial irrigation cost. This is quantified, on the basis of the average monthly precipitation in Benevento and the runoff water, equal to 453 €/year, by assuming a typical Italian water cost equal to 1.3 €/m^3.*
**** This cost has been calculated as difference between the installation of a condensing hot water boiler of 200 kW (13'295 €) instead of a traditional one (high efficiency, low temperature) of the same size (8'310 €).*

Selection of the most feasible Energy Efficiency Measures

In this section, on the basis of the results achieved in the previous study, the following selection criterion has been adopted: if the simple pay-back - by considering, when possible, the achievable government funding - is lower than 30 years, then the energy efficiency measure has been chosen.
According to this selection index, a last simulation combined:

- Reduction of envelope infiltration, by replacing the present windows' seals and by overhauling the windows frames.
- Installation of new windows, with roller shading systems, for the staircase. This EEM, even if not very profitable according to mere economic evaluations (i.e., simple payback equal to 25.1 years), it has been considered necessary in order to improve the indoor comfort conditions both in winter and summer.
- Installation of a condensing hot water boiler instead of a high-efficient traditional one.
- Installation - even if not mandatory, according to the Italian law, for this climate and these flow rates - of a rotary enthalpy heat recovery system inside the Air Handling Unit.

More in detail, a new numerical model (i.e., "idf file" of EnergyPlus) has been defined by combining the aforementioned EEMs, being these considered, according to Table 4, suitable for the improvement of the energy peculiarities of the present system Building/HVAC plant. The refurbished building shows the following energy-related outcomes:

- *Energy demand variation:*
  - winter reduction of primary energy for heating: 44'010 $kWh_{PRIMARY}$ (i.e., - 45.8%),
  - summer reduction of primary energy for cooling: 2'753 $kWh_{PRIMARY}$ (i.e., - 4.7%),
  - energy demand variation for annual air-conditioning: 46'762 $kWh_{PRIMARY}$ (i.e., - 30.2%).
- *Variation in operating costs:*
  - reduction of the winter operating costs: 3'636 € (i.e., - 42.9%),
  - reduction of the summer operating costs: 290 € (i.e., - 4.7%),
  - reduction of the yearly operating cost: 3'926 € (i.e., - 26.7%).
- Reduction in polluting emissions of $CO_{2\text{-equivalent}}$:
  - winter saving of polluting emissions: 10.36 tons of $CO_{2\text{-equiv}}$ (i.e., - 41.8%),
  - summer saving of polluting emissions: 0.90 tons of $CO_{2\text{-equiv}}$ (i.e., - 4.7%),
  - yearly saving of polluting emissions: 11.26 tons of $CO_{2\text{-equiv}}$ (i.e., - 25.6%).

In terms of comparisons between the present building and the refurbished one, all main outcomes of the performed energy-oriented refurbishment are reported in Figure 6:

a) energy demands for the winter heating;
b) energy demands for the summer cooling;
c) primary energy requests for electric uses;
d) primary energy requests for each use concerning the air-conditioning.

With reference to the primary energy required by the fans, the increment is due to the rotary heat exchanger, that induces a further pressure drop that increases the energy demand of auxiliaries.

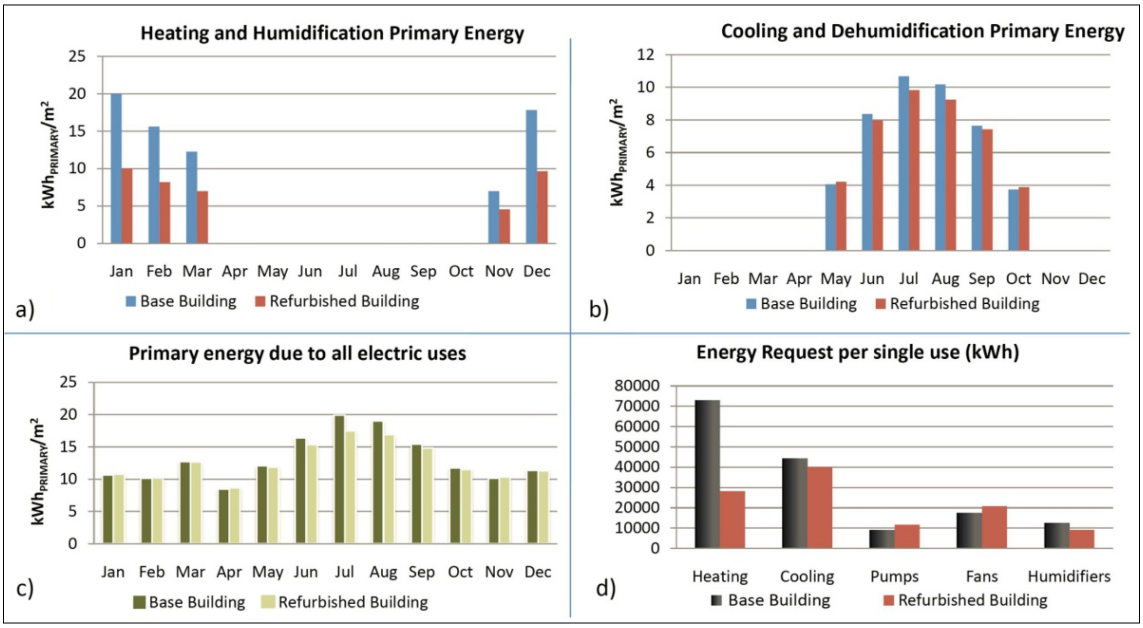

Figure 6 - Comparisons of energy demands of present and energy-refurbished buildings

The global building renovation has a cost equal to 55'415 €, with fundable 11'108 € (total amount of the incentive, achievable in five years). The annual operating costs for air-conditioning are reduced of about 3'926 €, with the following outcomes in terms of common indexes for feasibility study:

- Discounted Payback Period (discount rate equal to 3%/yearly): 14.3 years (Figure 7).
- Net Present Value, according to a time period equal to 25 years: 23123 €.
- Index of Profit (i.e., NPV/Investment): 0.42.

As further comment, we underline that:

- ✓ the considered EEM costs, taken from official catalogues and/or official prices for constructions, could be overestimated, being quite common a discount around 15-20%. This consideration increases the profitability;
- ✓ beyond the mere economic values, also the environmental benefits, the improved comfort conditions and the more efficient use of energy do profitable the proposed energy-oriented refurbishment.

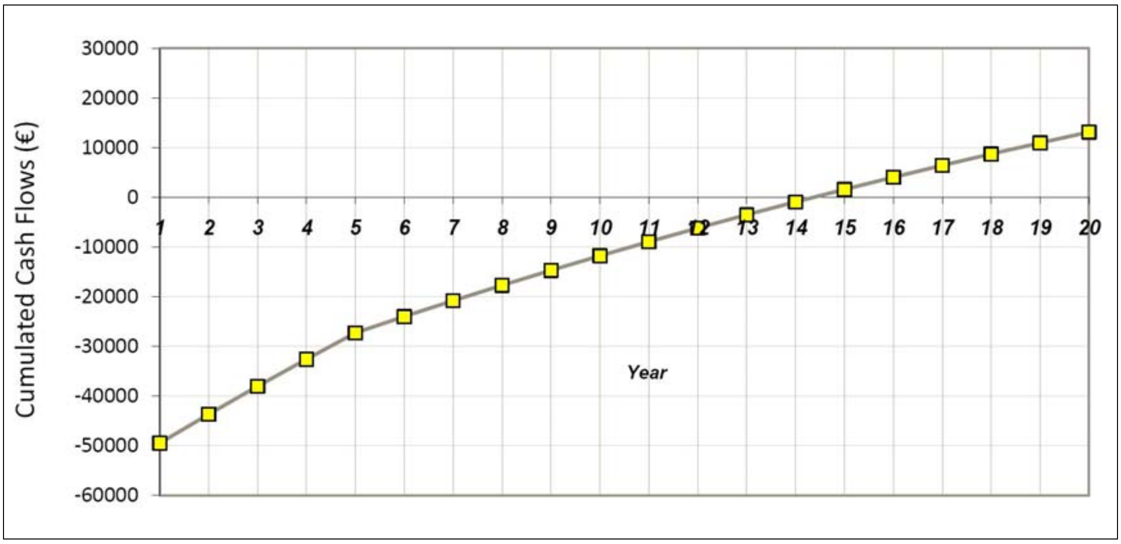

Figure 7 - Feasibility Study referred to the combined energy efficiency measures

Design of a Photovoltaic system

The previous study, concerning the low-cost building renovation under the energy point of view, has excluded the installation of a green roof on the building, because of a lack of convenience, even if, from a larger point of view (i.e. benefits connected to the local microclimate and reduction of pollution and dusts), the roof greenery would be useful.

However, also in order to integrate the present building electric demand, for the roof has been preferred the installation of a photovoltaic system. Indeed, this has been evaluated as the most energy efficient solution, given the flat roof and the climate.

Therefore, a photovoltaic system has been pre-sized, with a peak power equal to a 15 kWp, pv modules in amorphous silicon (a-SI), installed on the flat roof with a tilt angle equal to zero. It is important to underline that not the entire roof has been occupied, because the winter shadows caused by the stair block (Figure 8) would diminish the energy conversion.

Finally, a photovoltaic surface equal to 325 m^2 (the gross roof area is 493 m^2), sub-divided in three areas of 179, 102 and 44 m^2, has been considered. By taking into account the conversion efficiency of amorphous silicon, the peak power is around 15 kWp with an annual electrical production equal to 18'120 kWh, according to the solar radiation data reported in the Italian Standard UNI 10349 [22] for Benevento.

In Figure 9a, the monthly electric conversion by renewable is reported. Diversely, Figure 9b shows the electric demands of the present building, the refurbished building and of the last one that includes the photovoltaic system. Annually, the electric integration is estimated around 20% with reference to both the present and the refurbished buildings. These estimations include, of course, not only the electric uses related to the air-conditioning, but the overall electricity demands, and thus also the artificial lighting and the electric absorption by various devices.

According to common costs of ready-to-use systems of the photovoltaic technology, the total investment has been evaluated around 3000 €/kWp, and thus equal to 45'000 €. Presently, the photovoltaic systems in Italy have a cost ranging between 2000 - 3500 €/kWp, depending on the system size and installation peculiarities.

About the installation feasibility, the supposed photovoltaic system can be repaid, without incentives (i.e., only the "net metering" mechanism has been considered) in around 13.2 years. This is the Discounted Payback Period according to an electricity tariff equal to 0.229 €/kWh [21].

Presently (January 2014), indeed, incentives equal to a refunding of 50% of the plant cost can be obtained only by private clients. However, by considering a lifetime around 20-25 years, also this technology is considered quite profitable.

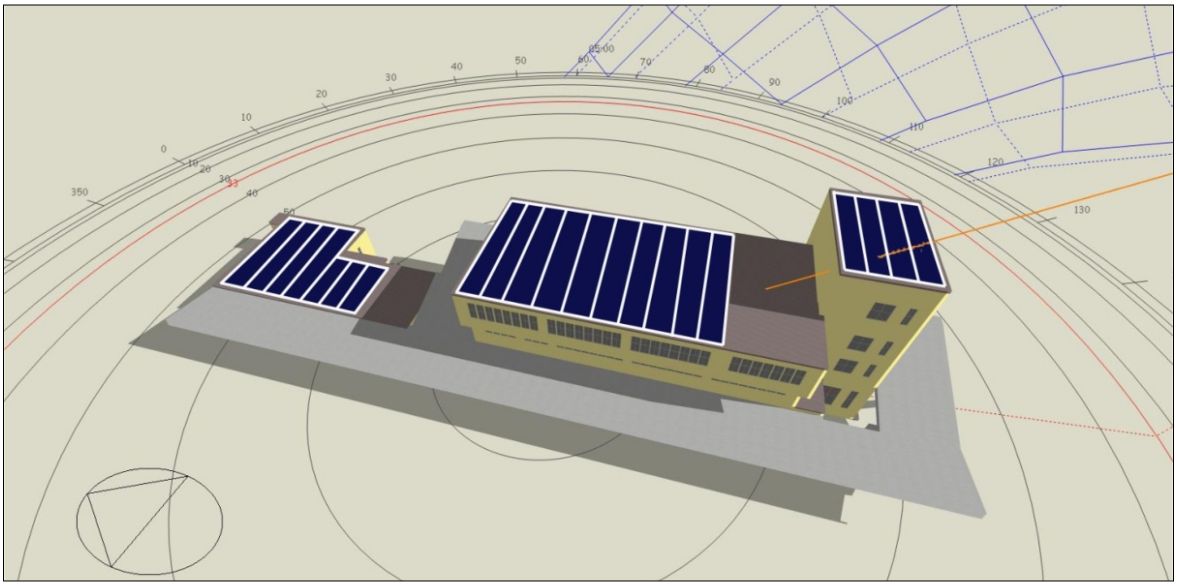

Figure 8 - Scheme of installation of amorphous pv modules on the building roof

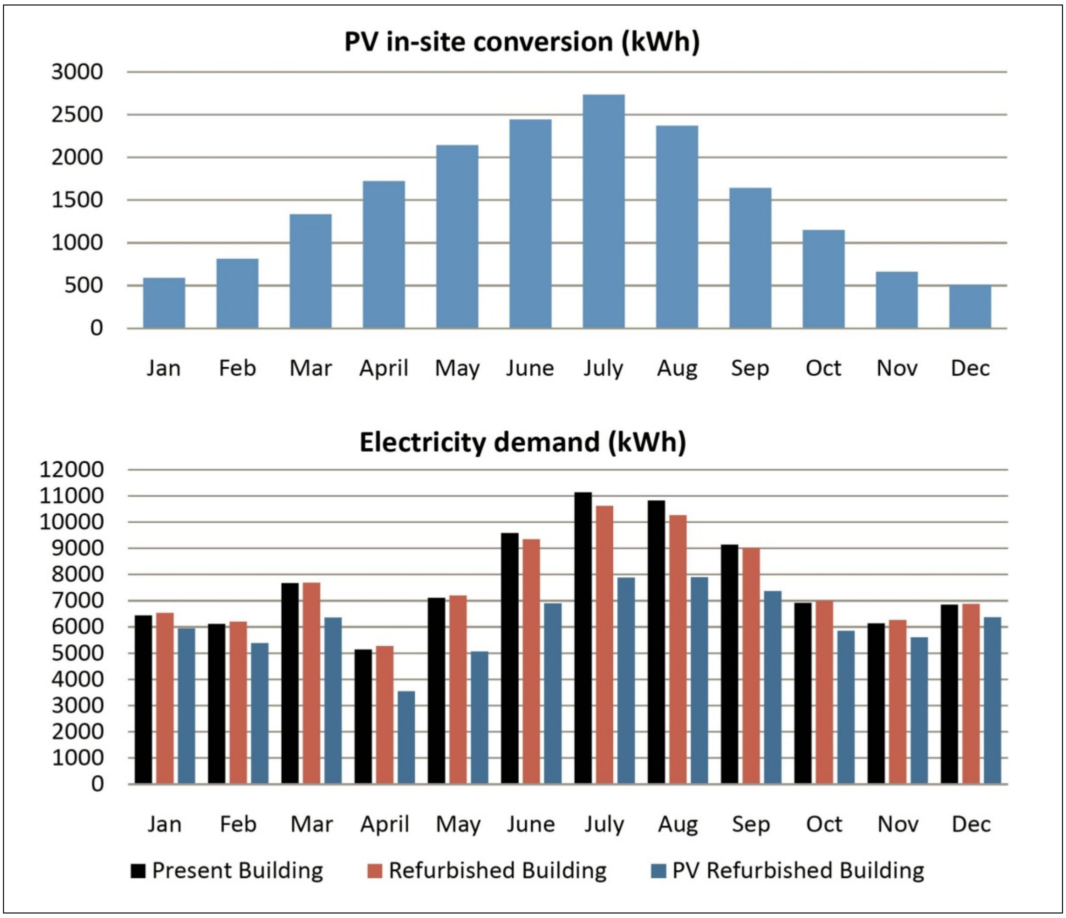

Figure 9 - Energy performance of the PV system in a-Si

Conclusions

The manuscript proposes a low-cost energy-oriented refurbishment of a Railway Station located in a Southern Italian City. The Appia Station of Benevento, built around 25 years ago, shows energy performances improvable, with reference to the present targets of energy efficiency, promoted by European and National Institutions toward a low-carbon future. Firstly, in order to improve the indoor conditions, above all in summer time, a new HVAC system has been proposed. More in detail, the latent and sensible indoor controls have been decoupled, by designing a dedicated outdoor air system with in-room fan-coils. Then, in order to improve the energy performances beyond the microclimatic control, some energy refurbishment actions, chosen among traditional ones (insulation of opaque envelope, replacement of windows, replacing of windows seals) and innovative ones (green-roofs) have been tested for improving the thermal-physical properties of the envelope. Moreover, other energy efficiency measures - such as the preference of a condensing water boiler compared to a traditional high efficient one and the adoption of a heat recovery exchanger - interested the HVAC system. By means of a proper feasibility study, the most profitable energy efficiency measures have been then selected and combined. Globally, the energy demand of the building - through the low-cost refurbishment - can be strongly reduced (i.e., -30.2% required primary energy for microclimatic control, -26.7% yearly operating cost, -25.6% polluting emission related to the building air-conditioning use). Furthermore, all the economic indexes are quite favorable, with a Discounted Payback Period around 14 years and thus completely feasible according to the lifetime of the proposed energy efficiency measures.
Finally, a photovoltaic system of 15 kWp has been designed, by selecting a solution with modules in amorphous silicon, installed on the roof area. Also this integration by renewable is quite convenient, by reducing around 20% the energy supply from the city grid. Without incentives, the photovoltaic system can be repaid in around 13.2 years.
The Appia Railway Station has a public use, so that - even if this is not strictly owned and/or occupied by the central Government – however an exemplar role can be seen, in order to support and diffuse the culture of energy efficiency for the whole citizenry. In this regard, the Member States' legislations, in compliance with the EU Directives 2010/31/EC and 2012/27/EC, will be the key factor. More information about the rate of development of the national plans for increasing the number of zZEBs, as well strategies and methods for promoting energy efficiency measures - concerning building envelope, active energy systems and energy from renewable sources - can be found at the EU website [23]. This is constantly upgraded with the last news, at both communitarian and national levels (e.g., Member States NZEB National Plans).

Nomenclature

EP_i	Yearly primary energy demand for space heating, per net surface area	[kWh/m^{2}a]
EP_e	Yearly primary energy demand for space cooling, per net surface area	[kWh/m^{2}a]
U_{VALUE}	Heat transfer coefficient, by transmission, of a building component	[W/m^{2}K]
SHGC	Solar Heat Gain Coefficient	[---]
HVAC	Heating, Ventilating and air-conditioning	
DOAS	Dedicated Outdoor Air System	
EEM	Energy Efficiency Measure	
SPB	Simple Payback Period	[years]
DPB	Discounted Payback Period	[years]
NPV	Net Present Value	[€]
IP	Index of Profit (i.e., Net Present Value / Investment)	[---]

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Curtain walls for building retrofit purposes

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Abstract

The first part of this paper describes how a façade of a 40 years old campus building in Prague has been replaced. This replacement served as an impulse for a) a discussion about energy performance, b) our own development work. As the replacement used quite high-quality curtain wall elements, the resulting situation in terms of energy performance of the building is quite different: the transmission heat losses have been minimized. The ventilation strategy has become a key factor in both the energy use and indoor environment quality. Given the low g-value of the high-quality glazing and efficient shading system, solar gains are not significant compared to internal heat gains. All these aspects should be considered advantageously when creating overall new energy solutions and setting targets for the building design.

The second part of this paper presents the development of the curtain wall element (panel) itself with a special focus on the environment. Renewable materials replacing aluminum and oil-based products with wood or wooden products are used to the highest possible extent together with active renewable energy components (PV). It is also possible to use units for de-centralized ventilation and other features (supporting grid for greenery, etc.) The paper contains thermal analysis, material solutions and environmental assessment of the newly developed products, and the lessons learned from prototyping.

Introduction

Since 1960´s, a significant share of facades on non-residential buildings has used light-weight curtain walls [1]. In the past, such solutions were characterized by a high energy-demand in terms of space heating. Moreover, the curtain walls with their large glazed areas and low thermal inertia have contributed to overheating the buildings and/or led to a significant cooling energy demand.

Many of these facades have already been replaced, however, many of them remain more or less in their original state, including more than 300 school buildings solely in the Czech Republic [2]. Other countries in Central Europe appear to be in the same situation. An advanced, industrialized way of assembly can be used for new and more efficient generation of building envelopes.

Real case study

One example is a 40 years old campus building in Prague that was refurbished during 2013 (Fig. 1). The old curtain wall with very poor performance was completely removed and replaced by a new element façade [3] of a significantly higher quality which meets today’s recommendations in matter of energy efficiency.

Building description

This tall building has a form of a simple cuboid with 15 floors and was finished in 1971. It was constructed using a curtain wall corresponding to existing requirements and the state of the technology. Probably due to high investment costs, the originally planned mechanical cooling of the building was not installed. The offices are oriented mainly to the SW façade. Seminar and meeting rooms are situated predominantly on the opposite side (NE). Ever since the building has been in use, problems with overheating and high energy consumption have been reported. Old elements were completely removed. New elements [3] differ in size (double width) and in overall quality (see Tab. 1). The new façade uses more appropriate size and type of window openings (Fig. 1). Motor-operated and locally/centrally controlled venetian blinds are integrated into the SW elements.

Figure 1 - left: the original curtain wall during disassembly (March 2013), right: the new curtain wall (July 2013). In both cases we can observe indoor and outdoor venetian blinds and different window openings.

Technical data and energy performance discussions

Table 1 compares main technical data of the original and new elements, respectively. Generally, the fundamental change in the quality of the building envelope implies necessary changes in the heating and ventilation of the building, otherwise the optimum and indoor quality cannot be reached. Table 2 presents the results of an indicative calculation of heat losses and heat gains for the selected floor of the building during the heating season. The results of this calculation are always subject to uncertainty associated with highly variable occupancy of the building; it is possible to make only rough estimates of heat gains from the office equipment, as well as of the volumetric flow rate of ventilation air.

It is also evident that even at very cold external air temperatures, internal heat gains (metabolic heat and office equipment) in daytime are significant. On the other hand, passive solar gains are generally low during this period. They are influenced by a low-intensity solar radiation and by the use of the glazing (low g-value) designed to prevent the risk of overheating in summer.

Table 3 illustrates a theoretical temperature of the external air above which there is no need to use conventional heating (at this temperature, heat gains and heat losses are balanced). Such temperature is surprisingly low, especially due to higher occupancy and the use of heat recovery in the mechanical ventilation system. In the case of not sufficient ventilation (B, D in Table 3) such threshold temperature could be even lower but the comfort requirements would not be fulfilled.

Additional use of the waste heat from local server units on the given floor (approx.10 kW in our case) would again change the results dramatically. It is necessary to use smart technical systems with intelligent control in order to actually exploit these heat gains

Table 1: Main data concerning the original and new curtain wall

Original curtain wall		
	Short characteristics	Thermal transmittance [W/(m^{2}K)]
Opaque part (42 %)	Polystyrene 60 mm	0.6
Transparent part (58 %)	Double glazed in metal frames	4.0
	Estimation taking into account significant thermal bridges	Mean value U_{mean} 3.0
Shading	Blinds alternatively placed on the interior side or between glazing panes, sun protective foil additionally placed on the interior surface	
New solution		
Opaque part SW: 48 % NE: 37 %	Mineral wool 140 mm, extruded polystyrene 50 mm	0.19
Transparent part SW: 52 % NE: 63 %	Triple glazing, insulating edge	SW: U_g 0.5 NE: U_g 0.6
		Mean value SW: U_{mean} 0.68 NE: U_{mean} 0.87
Shading	SW: integrated venetian blinds, motor controlled + movable indoor blinds NE: movable indoor blinds	

Table 2: Simplified estimation of specific heat losses for one floor, comparison of the original and new solution (according to EN ISO 13789)

	Original state 1) 2)	New state (2013)	Difference [%]
Specific transmission heat loss H_T [W/K]	1364	360	-74
Specific ventilation heat loss H_V [W/K] at full occupancy (120 person) 3)	550	550	0
Total specific heat loss H [W/K]	1914	910	- 53
Heating load at winter design temperature (-13 °C for Prague) [kW]	65.1	30.9	- 53
Estimated heat gains caused by persons and office equipment (90 students + 30 members of the staff) [kW]	14	14	0

1) Negative change in the quality in time (air-tightness etc.) is not taken into account.
2) Improvements of massive gable walls performed in the 1990´s have been considered.
3) Expected ventilation rate of 25 m^3/h.Pers.

Table 3: Selected theoretical operational mode and rough estimate of the limiting temperature of the external air for heating off (simplified approach)

	Number of persons per floor	Ventilation rate [m³/(h.pers.)]	Limiting temperature for heating (heating system no more in use) [°C]	
			No heat recovery from the exhaust air	Efficiency of heat recovery 70 % (in bracket: use of waste heat from server rooms)
A	120	25	+6	-6 (-13)
B	120	12.5 [1)]	-1	not applicable
C	60	25	+10	+5 (-8)
D	60	12.5 [1)]	+6	not applicable
E	30	25	--	+12 (-3)
F	0	0	--	-- (+4)

[1)] Estimation for insufficient natural ventilation, often even worse in reality.

Light-weight curtain wall made of wooden based panels

Inspired by the retrofit of the campus building, an alternative solution has been studied and proposed. System solution using a light-weight curtain wall of a panel type (Fig. 2) giving preference to wood-based materials has been designed in the framework of the Preseed06 research project at the University Centre for Energy Efficient Buildings [4]. The solution should primarily replace the obsolete type of curtain walling, but it can also be applied to new constructions. Main structural materials (panel supporting frame, exterior and interior design boards) and supplementary materials (thermal insulation and façade cladding, window frames and sash) of the proposed wall system are made of wood-based materials. The new panel is designed to allow easy assembly with the possibility of rectification. The system is executed with attention to detail. Where possible, the elements are prefabricated using precise CNC machines; main elements are made of advanced renewable materials. The joints connecting the panels enable installation without any extra work (no need of scaffolding on site) and thanks to flexible seals expansion movements are possible. Anchoring into the load-bearing ceiling plate is situated at the bottom part of the window sill. The panel is made in two variants: one with a window (transparent) and without it (opaque).

The panel can be used with different additional components. An opaque part can have the form of a ventilated façade equipped with active renewable energy components (photovoltaic, solar heat collectors), supporting grid for greenery purposes or traditional cladding materials (glass, wood, fiber-cement, etc.). Units for de-centralized mechanical ventilation with heat recovery, motor controlled external blinds and other devices can be used as well to improve the overall energy balance of the building.

Typically, the basic module (panel) is extended with an additional wall with a cavity on the interior side. The piping (electrical wiring, weak current systems, heating distribution) or heating bodies can be installed here. Furthermore, it can contain control elements of the blinds, heating, cooling and ventilation.

Figure 2: Scheme of a curtain wall made of wood-based panels.

Figure 3 left: The prototype during assembly - notice the cork insulation, right: View of the completed prototype No. 2.

Thermal analysis

The technical solution meets a higher level of current requirements on thermal protection of buildings in the Czech Republic. The total thickness of the panel is 250 mm in the basic version and the thermal insulation material is 220 mm thick. Depending on the type of the thermal insulation material, this construction reaches thermal transmittance values ranging from 0,22 to 0,19 W/(m^2.K). The quality of the thermal insulation can be further improved by using new generation materials (vacuum insulation panels, aerogels) which represent an advantage, as they can be placed into the protected position already in the factory without the risk of being damaged during the construction process. The "transparent variants" of the curtain wall are fitted with wooden windows Slavona Progression [5]. These windows are certified by the Passive House Institute and meet the requirements of the highest energy class A. The technical solution of the casement allows the window to be fitted without the frame being visible from the exterior. Triple glazing thermal transmittance ranges from 0.70 to 0.54 W/(m^2.K)

These properties help decrease the thermal loss through the building envelope by 70 % in comparison to the old type of the curtain wall. Annual energy demand for heating and related costs of heating can be decreased by more than 50 % by changing solely the building envelope.

Environmental assessment

One of the important goals of and the motivation for the development of the new generation curtain wall was to achieve better performance in comparison to traditional metal-based curtain walls in the environmental assessment. Replacing the aluminum and oil-based products by wood or wooden products is the first step in the process of creating an environmentally efficient design. Specifically, the design used laminated veneer lumber, oriented strand board, cork and wood-fiber insulation, fiber board, etc. (see Fig. 2). This curtain wall contains 93 % by weight of wood-based materials in its opaque variant and 65 % by weight in its transparent variant. The following chart (Fig. 4) compares the mass distribution of the materials in the wood-based curtain wall (design in question) and in the standard aluminum curtain wall.

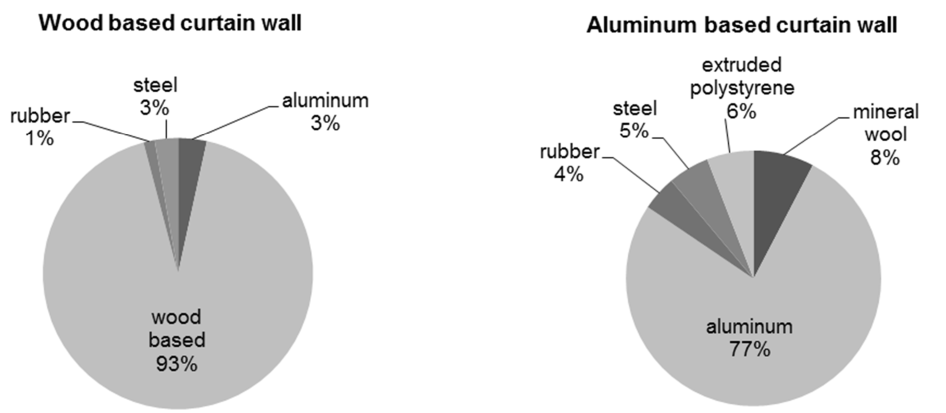

Figure 4: Mass distribution of the materials in the wood-based and aluminum curtain wall (an opaque variant) with the dimensions of 3.3 (h) x 1.5 (w) meters.

The next step consisted of an environmental assessment of the panel through a simplified analysis of the life-cycle assessment (LCA). For the purpose of the evaluation, the opaque variant of the curtain wall panel with its typical dimensions of 3.3 x 1.5 m has been chosen. The wood-based panel has been compared with other two alternatives for retrofitting a building.

- light-weight curtain wall made of aluminum-based panels
- aerated concrete masonry with ETICS with expanded polystyrene

Selected indicators describing the environmental performance of three different types of a building envelope are compared in the Table 4 and the Chart (Fig. 5). The wood-based panel achieves the best values in case of most of the evaluated parameters. For comparison, the energy consumption of the original panels was about 3050 MJ/m^2.

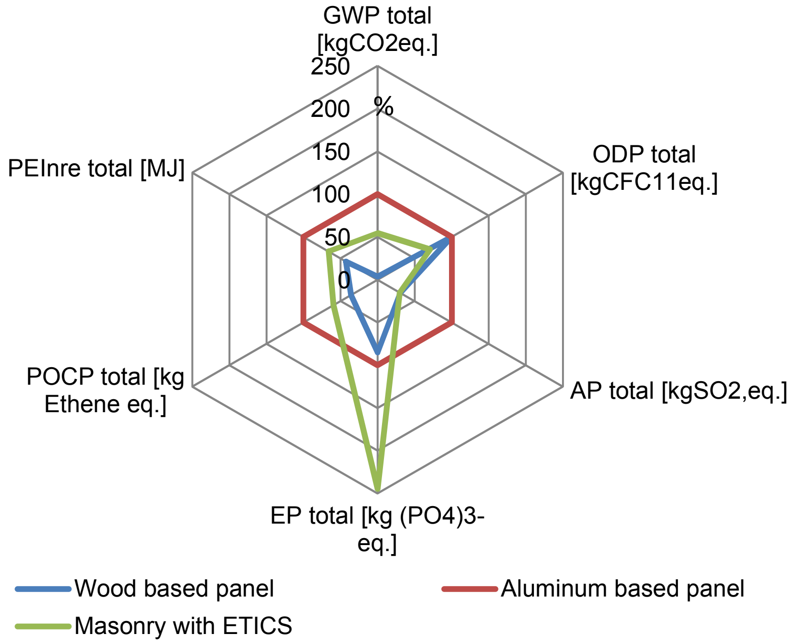

Figure 5: Simplified multi-criteria evaluation of the environmental quality on the net chart.

Table 4: Comparison of the two main environmental indicators

	Wood based panel	**Aluminum based panel**	**Masonry with ETICS**
Embodied energy, *PEI* [MJ/m^2]	1868	3225	2257
Global warming potential, *GWP* [CO_2/m^2]	6	168	92

Concluding remarks

We have shown that curtain walls meeting today's requirements and recommendations can result in a basically different energy performance. Ventilation strategy seems to be more important than the heat transmission (already significantly reduced), as far as indoor comfort and energy demand are concerned, especially in case of highly occupied buildings (schools, office buildings). Passive solar gains are no longer important as an energy source. In the campus building described in this paper, additional installation of a ventilation system with heat recovery is now under preparation. Hopefully, the waste heat from the local server situated in the building will be integrated into this action, too. Detailed monitoring of the resulting performance is planned as well.

The designed curtain wall system described in the second part of the paper will be tested as a prototype in the newly opened University Centre for Energy Efficient Buildings of the Czech Technical University in Prague [4]. The test will focus on thermal transmittance and thermal inertia, humidity and moisture related problems and the technology of assembling. Development should continue in order to reach high flexibility in sizing, to improve external design and to integrate additional features. Special attention will be paid to the problem of fire-safety. It can limit the use to a certain extent in line with the national legislation. Naturally, the proposed solution is suitable both for old and new buildings.

Acknowledgment

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Analysis of generic and energy-efficient building retrofit activities and motivation of office building owners

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Abstract

In recent years extensive empirical investigations have been made about building retrofit activities and behavior in the residential sector. However such empirical data has been available much less in the non-residential sector so far. Therefore, an empirical study has been carried out by the authors in order to investigate the situation of office and administrative buildings in the city of Zurich. The goal of the study was to gather energy-relevant determinants of a sample of office buildings, in terms of energy increasing factors on the one hand and in terms of energy-reducing factors on the other hand. Hence, we analyze both, the equipment of office buildings with appliances and building technologies and the retrofit behavior as well as the management strategies of building owners and managers of such buildings. In particular, we investigate motivation and influencing factors which lead to retrofits in general and to energy-saving retrofits: First, we describe the hitherto retrofit activity regarding office and administrative buildings in terms of retrofit rates and their break-down on different types of retrofit measures. Second, we portray goals and motives which influence retrofit and describe similarities and differences among owners, managers or buildings with specific attributes. Third, by regression analysis, we empirically confirm characteristics of buildings and owners or managers which have been stated to determine retrofit outcomes in previous, mostly not empirical analyses. Finally, we explore the barriers to energy-efficient retrofit activities.

Introduction

While, in recent years extensive empirical investigations have been made about building retrofit activities and behavior in the residential sector (see for instance Banfi et al. 2011 [1]; Banfi et al. 2012 [2]; Ott, Jakob et al. 2005 [3] for Switzerland), empirical data regarding the non-residential sector can only be found on heating and current demand, optimization potential, and the development of optimization potential during the last years (Jakob et al. 2010 [4]). Data on triggers, motives, barriers, retrofit activity, and the equipment with building technology has not yet been sufficiently collected regarding non-residential buildings.

Therefore, an empirical study has been proposed and carried out by the authors [5]. By means of an online survey the situation of office and administrative buildings in the city of Zurich was investigated. The survey collected data on basic features of the buildings, condition of building envelope and building technology, equipment with energy relevant attributes as well as goals and motives of building owners and managers (see [5] for details). The number of completed forms added up to 278, which corresponds to a return rate of 18.7%.

The remainder of the article is organized as follows: The section “Retrofit Activity 2000 - 2012” summarizes the retrofit measures analyzed in this study. In the section “Motivation for Retrofit Activities and Choice of Measures” the behavioral drivers for the undertaken retrofits are presented. A multivariate model is discussed in the section “Drivers of Retrofit Decisions”, which investigates the influence of a larger set of explanatory variables on the retrofit decisions. In a similar vein, the variables determining whether a building is equipped with ventilation and air conditioning are identified in the section “Drivers of Ventilation and Air Conditioning”.

Retrofit Activity 2000 - 2012

By means of methods of descriptive statistics the retrofit activity between 2000 and 2012 is characterized. Table 1 gives an overview of the retrofit activity regarding office and administrative buildings in the city of Zurich and, in comparison, the rate of energy-saving retrofits of the building envelope elements of residential buildings, broken down to the different building elements that were taken into account.

The different building elements differ in their retrofit rates due to their different lifetime: Heating systems, lighting installations and windows are renewed more frequently than façades, roofs and basement ceilings. Likewise, flat roofs are more often repaired than steep roofs. Reasons for these differences are different (technical) lifetimes, technological developments and specific needs and preferences of building owners and users (see also the sections “Motivations” and “Drivers and Retrofit Decisions”).

The estimated rates of all types of retrofits and the estimated rates of energy-saving retrofits are close together for the building elements windows and steep roof of office buildings. This means that for these building elements retrofit measures imply nearly always an energy-saving measure. In the case of the building elements flat roof, basement ceiling, ventilation and air condition, lighting and above all façade it occurs, however, more often that the retrofit measures don’t signify an improvement of the building’s energy efficiency. Significant energy-efficiency improvements of the heating system or a switch to renewable energy resources are very rare in the results of our survey, since only the change to a new, more energy efficient heating system was considered to be an energy-saving measure.

The comparison of the rates of energy-saving retrofits concerning the building envelope of office and residential buildings shows that the rates are close together with the exception of the building element windows, where energy-saving measures are realized more often for residential than for office and administrative buildings (3.5% p.a. instead of 2.0 – 2.8% p.a.).

Estimation according to the survey of office and administrative buildings: Retrofit in the period 2000 – 2012 [5]				**Comparison with residential multi-family buildings [2]**
Building element	**Rate of all types of retrofit [%/year]**	**Rate of energy-saving retrofits [%/year]**	**Share of energy-saving retrofits as of all retrofits [%]**	**Rate of energy-saving retrofits [%/year]**
façade	1.7 – 2.5	0.6 – 1.1	35 – 44	1.0
windows	2.4 – 3.2	2.0 – 2.8	83 – 87	3.5
steep roof	1.5 – 2.5	1.1 – 2.0	73 – 80	2.0
flat roof	2.4 – 3.7	1.6 – 2.8	53 – 75	2.4
basement ceiling	0.8 – 1.4.	0.5 – 1.0	62 – 71	1.1
heating, hot water generation and heat distribution	4.3 – 5.2			
heating	3.5 – 4.4	0.3 – 0.9	9 – 20	
ventilation and air condition	4.1 – 5.2	2.5 – 3.7	61 – 71	
lightning	4.1 – 5.0	2.4 – 3.4	61 – 68	
solar panels	0.1 – 0.4			

Table 1: Retrofit rate and rate of energy-saving retrofits for office and administrative buildings [5] and, in comparison, the rate of energy-saving retrofits of the building envelope elements of residential buildings [2] (in percent per year).

Motivation for Retrofit Activities and Choice of Measures – Statements of owners and managers

278 building owners or building managers in the city of Zurich anwered questions about retrofit activities, choice of measures as well as goals and motivations.

Reasons to retrofit

The most important reason for retrofit activities is simply the need to repair or replace one or several building elements due to aging. Almost equally important is the wish to improve the level of comfort or the environmental profile of the building, which, at least in comparison to new buildings, is lower in existing buildings (depending on the construction period and past retrofits). Also important in the city of Zurich, where property prices are high, is the wish to increase the useful floor space.

Choice of measures

Decisions about retrofit measures are mostly made on rather high organizational levels of the building owning company or enterprise or, in the case of individual private ownership, by the owners themselves. These owner-decision makers are quite well informed: Only a small minority of decision makers consider themselves insufficiently informed or for other reasons not thoroughly qualified to make good retrofit decisions. Retrofit know-how is mostly provided by architects, engineers, specialized company or enterprise units or building companies. State-run energy agencies are only contacted in about one fifth of all occasions.

The most important guidelines for retrofit decisions are legal regulations, which require energy saving measures under certain conditions (replacement of building elements, amount to be invested). Only in about half of the occasions decision makers systematically compare several possible retrofit measure or packages of retrofit measures. Actually, in one quarter of all occasions the best package of retrofit measures is considered to be obvious.

According to the responding building owners and managers, ecological improvement (mostly in terms of increased energy-efficiency, partly also in terms of using renewable energy) of buildings is more likely improved in the course of retrofit activities if:

- ecological improvement comes automatically due to technological progress, for example when replacing windows,
- legal regulations enforce ecological improvement,
- ecological improvement goes along with comfort improvement,
- ecological improvement does not lead to higher cost than other possible measures,
- ecological improvements are not especially difficult due to the building's characteristics.

Strategic targets concerning environmental friendliness and government seemingly also aid to support ecological improvements.

Drivers of Retrofit Decisions

The uni- and bivariate illustrations and analyses described in the previous sections have their limits when it comes to examining the drivers of retrofit decisions. For example, the data shows that different owner groups behave slightly differently when it comes to retrofit. At the same time, we found that owner groups put different emphasis on different goals concerning their buildings (such as rate of return and energy use). But are these differences in goals the reason for the differences in behavior? Multivariate models help to address this kind of questions. Therefore, in addition to the uni- and bivariate analyses summarized above and described in more details in [5] we also examine by multivariate regression analysis several presumptive drivers of retrofit decisions which appeared in the previously conducted exploratory interviews and/or the reviewed literature.

The econometric model

Looking at a thirteen year time period from 2000 to 2012, we model retrofit decisions by means of a discrete variable with three possible values:

0: no retrofit measures during the considered time period
1: retrofit not leading to energy-saving[1] during the considered time period
2: retrofit leading to energy-saving during the considered time period

Using this coding, for each building retrofit decision about seven building elements are recorded separately. In the model, retrofit decision is used as the outcome (i.e. dependent) variable. The independent explanatory variables contain information about the type of building element, the year of construction, the location, some technical attributes of the building, owner category and the owners' goals concerning rate of return, costs as well as environmental friendliness. The full list of explanatory variables is given in Table 3 in the next section.

Decisions concerning the seven building elements are all integrated in one model, in order to take into account dependencies between decisions concerning different building elements. Based on the data structure presented in Table 2 below, a multinomial logit regression with robust standard errors is used to estimate the probability of conducting an energy-saving retrofit versus conducting a non-energy-saving retrofit or no retrofit at all.

	Outcome Variable	**Explanatory Variables**				
Building ID	**Retrofit Decision**	**Building element (Control Variables)**	**Built before 1931**	**City Center**	**Private Ownership**	**… etc.**
1	1	façade	no	yes	no	…
1	2	windows	no	yes	no	…
1	0	roof	no	yes	no	…
1	0	basement ceiling	no	yes	no	…
1	1	heating	no	yes	no	…
1	0	ventilation and air condition	no	yes	no	…
1	0	lightning	no	yes	no	…
2	0	façade	no	no	yes	…
2	1	windows	no	no	yes	…
2	0	roof	no	no	yes	…
2	0	basement ceiling	no	no	yes	…
2	1	heating	no	no	yes	…
2	1	ventilation and air condition	no	no	yes	…
2	0	lightning	no	no	yes	…

Table 2: Exemplary illustration of the data structure for the multinomial logit regression analysis with robust standard errors. "no" is coded with 0, "yes" is coded with 1.

Results

The regressions results show which characteristics of buildings, ownership and use can be shown to statistically influence the retrofit outcome. Moreover, the influence of the goals the owner or manager stated to be important in the survey was examined, such as revenue, cost and environmental friendliness (low energy usage).

Table 3 gives a summary of the regression results. The first and second column list the groups of explanatory variables, whereas the arrows in column three to five indicate whether a statistically signifcant influence on the respective chance was found an in which direction it goes. An upward

[1] retrofits leading to energy-saving include the installation of solar panels

arrow indicates a positive influence, a downward arrow a negative one. From the results presented in Table 3 the following findings can be stated:

- In buildings constructed before 1931, the façades were retrofitted more often than in other buildings. However, energy-saving measures for the façades were performed less often. In buildings constructed after 1970, an energy-saving retrofit of the ventilation or air conditioning systems was performed more often than in other buildings.
- Buildings under preservation order show a much lower probability for energy-saving retrofit of the façade as compared to other buildings. In exchange, the probability for energy-saving measures of the heating system is higher.
- Energy-saving retrofit of the ventilation and/or air conditioning system is more probable for larger than for smaller buildings. This effect of scale is not observed for the other building elements.
- The existence of a ventilation and/or air conditioning system raises the general probability that energy-efficient retrofit measures are performed. A reason could be that ventilation and/or air conditioning system are rather installed in buildings with users that have an increased demand for comfort.
- Different behavior can be observed depending on the type of ownership: Energy saving measures are conducted more often by private and non-professional owners as well as companies owning the building (not real estate), as compared to real estate agencies and single users. However, no difference was identified when comparing the rates of non-energy saving measures.

The retrofit behavior of building owners and managers can furthermore be explained by different goals that they specified in the survey: A high priority for low energy use of a building increases the prospects of retrofit in general as well as the prospects of energy-saving retrofit. While a priority for high-quality architecture leads to higher prospects for energy-saving retrofit, a priority for high rates of return leads to lower prospects. Finally, a high priority of the goal “low retrofit costs” raises the prospects of energy-saving retrofit, but only if retrofit measures have to be performed anyway.

		Influence of the explanatory variable on the chance (odds ratio) for			
Explanatory variable		**non-energy-saving vs. no retrofit**	**energy-saving vs. no retrofit**	**energy-saving vs. non energy-saving**	**Remarks:**
Building Attributes	Built before 1931	↑	↓	↓	Only true for façades
	Built after 1970		↑	↑	Only true for ventilation and air condition
	Built after 1980		↓		Only true for building envelope
	Flat Roof	↑			Only true for roof
	Larger than $1000m^2$		↑		Only true for ventilation and air condition
	Ventilation or air condition installed		↑		
	Preservation order	↑			Only true for façade retrofit
			↑	↑	Only true for heating retrofit
	City center			↓	True for all buildings elements
			↑	↑	Only true for ventilation and air condition
Ownership & use	Private and Non-Professional		↑	↑	
	Company, non-real estate		↑	↑	
	Real estate company				
	Only one user				
Goals important to owners	High rates of return		↓		
	Low retrofit costs			↑	
	Low energy usage	↑	↑	↑	
	High-quality architecture		↑	↑	

Table 3: Summary of results of the multinomial logit regression analysis with robust standard errors
↑ Positive influence (with statistical significance)
↓ Negative influence (with statistical significance)
Empty table cells indicate that no significant effect could be found.
Data: 1'238 retrofit decisions made between 2000 and 2012 concerning seven building elements (listed in Table 2) of 204 buildings in the city of Zurich.

Drivers of Ventilation and Air Conditioning

By logistic regression analysis we furthermore estimate the probability of the buildings being equipped with a ventilation and/or air conditioning as a function of different building attributes. Table 4 illustrates the tendencies (more details are documented in [5]). It was found that:

- Office or administrative buildings built after 1970 as well as large buildings (more than 1000 m^2) are significantly more often equipped with a ventilation and/or air conditioning system than other buildings. These buildings often also possess lowered ceilings or double floors which raise the necessity and therefore the probability for ventilation or air condition.
- Buildings located in the city center show a higher probability for a ventilation and/or air conditioning system than other buildings. This could be due to higher requirements for comfort and standard in the prestigious city center.
- Buildings in possession of private and non-professional owners are less often equipped with ventilation and/or air condition than those in possession of companies.
- An energy-saving retrofit of the building envelope between 2000 and 2012 finally raises the probability of a building to have a ventilation and/or air conditioning system installed.

	Influence of the explanatory variable on the chance for …	
Explanatory variable	**Ventilation installed**	**Air conditioning installed**
Built after 1970	↑	↑
Larger than $1000m^2$	↑	↑
Preservation order		
City center	↑	↑
Private and non-professional building owners[2]	↓	↓
Other building owners[2]		
Own use of the building owner		
High rates of return		
Energy-saving retrofit of building envelope between 2000 and 2012	↑	↑
Lowered ceilings or double floors	↑	↑

Table 4: Summary of the results of the logistic regression analysis.
↑ Positive influence (with statistical significance)
↓ Negative influence (with statistical significance)
Empty table cells indicate that no significant effect could be found.
Data: 321 buildings in the city of Zurich.

Conclusions

An empirical study on the situation of office and administrative buildings in Zurich has been conducted and data have been analyzed using different methodologies. The retrofit rates of different building components as well as the corresponding effects in terms of energy savings were assessed by means of descriptive statistics. Thereby, windows and steep roofs were found to be the components whose retrofit leads to associated energy-savings with the highest probability. Dominant drivers for retrofits in general can be found on both the technical level (lifetime of components and technological developments) and in the preferences of the building owners such improvements to the level of comfort and the building’s environmental footprint, or an increase of the useful floor space. Furthermore, legal regulations have been found to play a important role. Ecological improvements are most likely to happen as a “by-product” of other measures or if enforced by tailored policies. A more detailed multivariate analysis was performed to determine the influence of a large variety of drivers such as the building’s age and attributes, the ownership status and the goals most important to the owner. Similarly, correlations between the existence of a ventilation and/or air conditioning system and different building attributes could be found.

[2] Comparison group: companies

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Session

Modelling and Evaluation

Calibration of Building Simulation Models: Assessment of Current Acceptance Criteria

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Abstract

In this paper, the most used acceptance criteria in calibration of building simulation models are introduced and tried out by means of a practical exercise. In order to simplify the process of obtaining "simulated data" and to avoid carrying out a formal calibration procedure; two yearly testing profiles (hourly time scale) are created from real building electrical metered data (¼ hour profile). Both testing profiles represent two model responses that could possibly be obtained in a common calibration procedure.

The objective of this work is to test the capabilities of the method to determine (1) the model adequacy to represent an existing situation; (2) the reliability of the model when predicting a future or different scenario and also (3) the ability of the method to orient the practitioner to upgrade the model when it provides a non-satisfactory response.

To do this, the real accuracy of both testing profiles is verified by means of a complementary statistical bin analysis. This crosschecking analysis allows highlighting the strengths and weakness of the current criteria and determining whether they need to be revised, modified or complemented.

At the end of the analysis, it is concluded that the capabilities of the current acceptance criteria are limited because don't provide any satisfactory answer, indication or clue for none of the three points aforementioned and some other complementary tests (such as bin analysis) must be implemented and performed in order to properly declare a model as calibrated.

Introduction

In building modeling and simulation, calibration consists in adjusting or "tuning" the parameters of an existing building model through several iterations until it agrees with recorded energy use and demand data within some predefined criteria (adapted from [1]). The process involves the use of a computer simulation tool to create a model of energy use and demand of the facility. This model is adjusted over a reference period, which is usually called "baseline period". Figure 1 shows a generic scheme of the process.

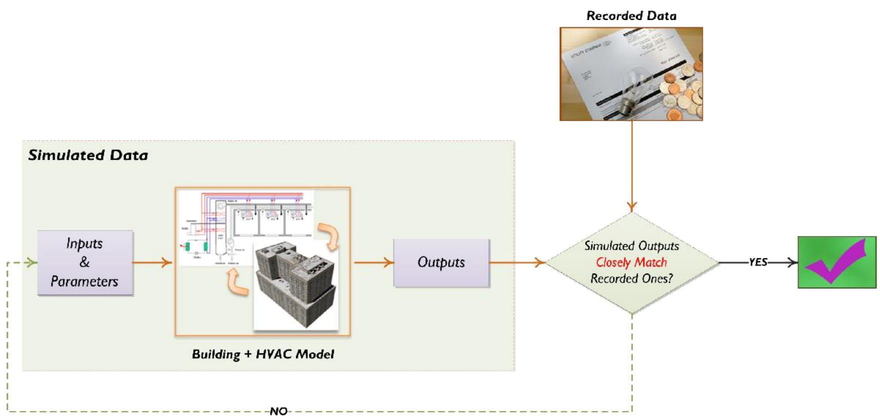

Figure 1 - Calibration process scheme in building simulation

Whole-building calibrated simulation is an approach proposed by the three major standards of energy performance measurement and verification for determining ECOs savings [2],[3],[4]. Its use is recommended when the energy impacts of ECOs are too complex or costly to evaluate by means of measurements. While this is the most common use, it can also be applied to performance analysis in other stages of the building life cycle such as: commissioning, continuous performance verification, fault detection, etc.

Regardless of the purpose for which it is required, the ultimate goal that must fulfill any calibrated simulation model is: *to represent accurately the energy use and demand of an existing building within a reference or baseline period so that it is able to predict accurately the energy use and demand for a future or post retrofit period under the same or different conditions* (i.e. weather, control strategies, HVAC equipment replacement, etc.). A representation of this issue is illustrated in Figure 2.

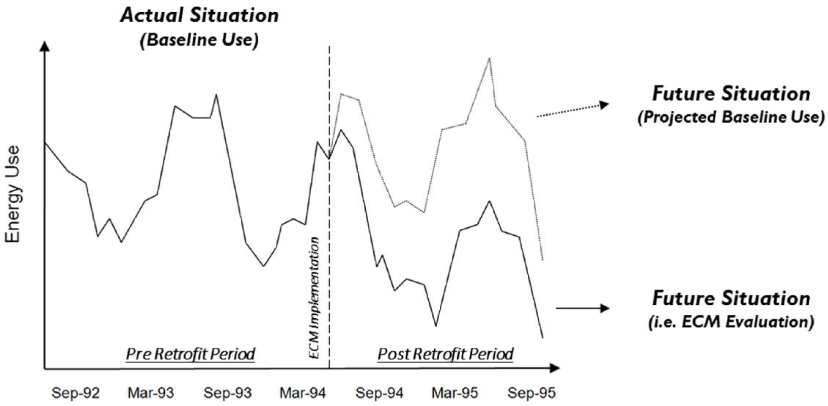

Figure 2 - Determining savings (adapted from ASHRAE,2002)

In the related literature, it can be found several approaches and methodologies applied to real case studies which show a good agreement in terms of accuracy when representing an existing situation; however, no study to date presents any evidence about the issue of whether this achieved accuracy can be transferred to predictions of a new scenario (i.e. projected baseline use and/or evaluation of intended ECM savings). Despite this issue is of great importance; some of the most important guidelines such as ASHRAE (2002) completely ignore this aspect [5].

In order to propose a solution to this issue, it is imperative to understand the overall process (Figure 1) and identify the main barriers that attempt against the successful completion of the calibration process (Figure 2). In practice, they can be summarized into two main constraints:

1. To common building energy data is a highly under-determined problem that would result in a non-unique solution [6].

2. The definition of accuracy criteria is a complex issue and, to date, it is impossible to determine how close a tolerance needs to be to fulfill the calibration objective [1].

The under determination is an inherent condition that is present in the whole calibration process and cannot be bypassed. In mathematics, a system of linear equations is considered underdetermined if there are more unknowns than equations. It means that an infinite combination of unknowns may satisfy a given set of equations.

So in building calibration, if the acceptance criteria are not able to identify the real correctness of a set of unknowns even if the they are providing a response within a desired tolerance range for an existing situation, then the predictions of the model for a future situation will not be reliable and therefore the calibration targets are not being achieved.

This paper covers and tries to give an answer to issue. It starts presenting the current and most used acceptance criteria. Then a complementary evaluation method is proposed, tested and the obtained results of this evaluation are confronted with some requirements that a model should fulfill. All this in order to: determine the suitability of the acceptance criteria and establish how their results must be interpreted.

Current Acceptance Criteria

The most used acceptance criteria to determine whether a building simulation model may be considered calibrated or not, consist in calculating and comparing (with respect to a maximal tolerance) 2 statistical indexes: Normalized Mean bias error ($NMBE$) and Coefficient of Variation of the Root Mean Square Error ($CV(RMSE)$).

The first of the indexes, the Normalized Mean Bias Error ($NMBE$) is defined as the mean difference between the measured data values and model simulated values, normalized by the mean value of the measured data [7].

$$NMBE = \frac{\sum_{i=1}^{n} \frac{M_i - S_i}{n}}{\bar{M}} \quad (1)$$

Where: M_i is the measured value during the i^{th} period; S_i is the simulated value during the i^{th} period; $\bar{M}$ is the measured average during the period and n is the number of available data points (or periods)

$NMBE$ measures how close the energy use or demand predicted by the simulation model corresponds to actual building data. The main drawback of this index is that it does not capture effects where positive and negative errors cancel each other out (offsetting errors).

Thus, an index that captures offsetting errors is necessary. This is the Coefficient of Variation of the Root Mean Square Error ($CV(RMSE)$) wich corresponds to a normalized measure that quantifies the degree of dispersion of a set of predicted values around the mean of the observed values. Notation is the same as shown above.

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^{n}(M_i - S_i)^2}{n}}}{\bar{M}} \quad (2)$$

So, according to these criteria, the combination of $NMBE$ and the $CV(RMSE)$ can determine how well the model predicts whole-building energy use. The lower the $NMBE$ and $CV(RMSE)$, the better the calibration.

In practice, both indexes are evaluated for different end uses (usually electricity and fuel) and at different time scales (annual, monthly, hourly, etc.). Table 1 specifies the acceptable tolerances proposed by the three standards dealing with calibration [2],[3],[4].

Table 1 - Commonly used calibration tolerances

Index	Waltz (2000)	ASHRAE 14	IPMVP	FEMP
MBE_{year}	± 5%			
MBE_{month}		± 5%	± 20%	± 5%
$CV(RMSE)_{month}$		± 15%		± 15%
MBE_{hourly}		± 10%	± 5%	± 10%
$CV(RMSE)_{hourly}$		± 30%	± 20%	± 30%

In addition to the calculation and comparison of these statistical indexes, some other complementary techniques have been proposed by different authors. For example, to enlarge the set of tolerances depending on the energy uses (lighting, cooling, heating, fans, etc.) and tuning periods (monthly, daily, hot period, cold period, etc.) [1].

US DOE (2008) [3] proposes the use of any or all of four graphical comparison techniques summarized in Bou-Saada and Haberl (1995) to compare a simulation's output with real data. These techniques are: hourly loads profiles, binned interquartile analysis using box-whisker-mean plots, weather day-type 24-hour profile plots and three-dimensional surface plots. Some of these techniques require significant post-processing of data and in this paper are not discussed.

Finally, according to the current acceptance criteria, if a model is able to provide results within the proposed tolerances for MBE and $CV(RMSE)$ for hourly, monthly and annual timescales, then might be declared as calibrated and its predictions may be considered as accurate and reliable**.** In the next sections this approach is tried out.

Material and Method

Proposed Analysis

The proposed analysis considers the evaluation of both statistical indexes (MBE and $CV(RMSE)$) at different time scales (annual, monthly and hourly) in order to determine the adequacy level of a "hypothetical model response" with respect to real metered data. For this purpose, two electrical ¼ hour profiles (corresponding to reference building) have been taken, handled and used as model response (simulated data) and metered data.

The term *"model response"* makes reference to a whole-building electrical hourly profile which can be considered as *a candidate solution obtained during a calibration procedure* and for which, is required to determine its actual accuracy and reliability. The reason why this approach was chosen is certainly to avoid performing a calibration procedure (a matter of time) but also because, the quality of the candidate model response is previously known and the way how this aspect is shown by the acceptance criteria indexes is required. In this analysis two "model responses" are tested. Details about how they were obtained are given below.

Reference Building

The reference building (commonly known as DM28) corresponds to a tertiary building located in the city center of Brussels, Belgium. It accommodates the European commission for energy and transport.

Figure 3 - Exterior scene of the studied building (DM28)

The building comprises 10 stores above ground (9 corresponding to offices and 1 to technical rooms) and 3 underground parking. Its fully enclosed area is about 18700 m^2.

According to building services and operating schedules, the building can be divided in 3 zones: The first one corresponds to the entrance hall of ground level (about 150 m^2), the second one to office's floors +1 to +8 and the remaining ground level (about 10200 m^2) and the third one to the 3 underground parking (about 7600 m^2). Building services and main electrical consumers comprise: artificial lighting, office's appliances and HVAC systems. Table 2 shows the operating schedule per service and zone.

Table 2 - DM28 operating schedules

Service	Entrance Hall	Offices	Parking	Day Type
Lighting and appliances	06:00 – 22:00	06:00 – 22:00 (*)	06:00 – 22:00	Weekdays
	10:00 – 19:00	10:00 – 19:00 (*)	–	Weekends and Holidays
HVAC system	06:00 – 22:45	08:00 – 20:00	08:00 – 20:00	Weekdays
	10:00 – 19:00	–	–	Weekends and Holidays

(*) In this zone, lighting is manually controlled by occupants but out of this period BEMS shuts it off automatically.

Artificial lighting is present in the whole-building being the "entrance hall" negligible to the total consumption due to the small surface it serves. Appliances are only present in "office's zone". HVAC system serves almost all the building excepting technical rooms. It comprises: Hot water production (3 gas boilers and auxiliaries), cold water production (2 water cooled chillers and their respective cooling towers and auxiliaries), mechanical ventilation (5 AHUs and 4 extraction fans), terminal units (4 pipes FCUs and hot water convectors) located at "office zone" and 2 air heaters located in parking spaces.

In order to complement the schedules shown in Table 2 and to understand better the HVAC operation and its impact on the electric usage, it must be indicated:

- The heating plant is stopped when outdoor temperature goes over 16°C (summer limit temperature). The three boilers and all the circulators and pumps are started (24/7) when outdoor temperature goes below 3°C to avoid freezing.
- The cooling plant is automatically switched off as soon as the outdoor temperature is below 14°C.

Figure 4 shows electrical power demand profile recorded for year 2009. It has been obtained from a ¼ hour profile belonging to reference building.

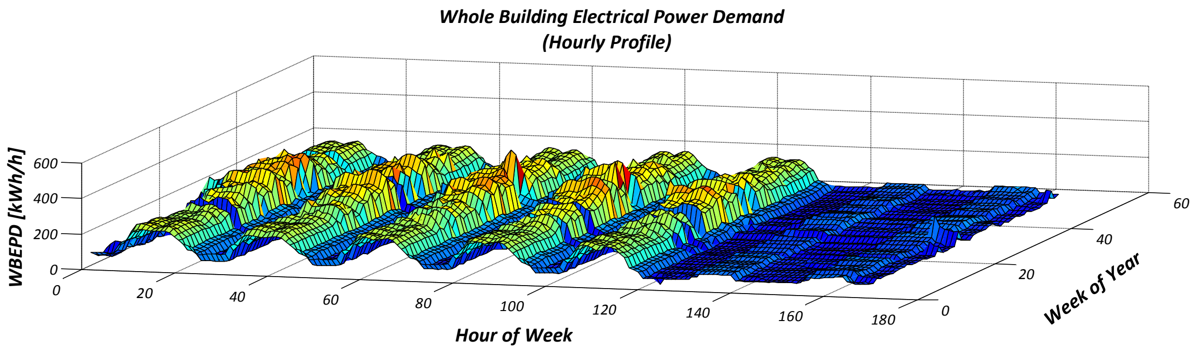

Figure 4 - Whole-Building Electrical power demand – Surface plot arranged by weeks

Weekly profile plotted in Figure 4 shows a clear impact of BEMS in the repeatability of 5 weekdays and 2 weekend daily profiles, the characteristic shape and order of magnitude of each one; and also a seasonal effect can be perceived when going to through the calendar year (week of year axis). This fact verifies the information of operating schedules provided in Table 2.

Characterizing Daily Load Profile

Daily load profile experiences a very clear behavior for both types of days. Even if weekdays seem to be very influenced by occupants' actions (because of the load shape) is also true that several periods during the day can be recognized where some consumptions must surely be allowed or not in function of occupants' presence.

Figure 5 shows two average profiles (week and weekend) containing some recognized daily periods.

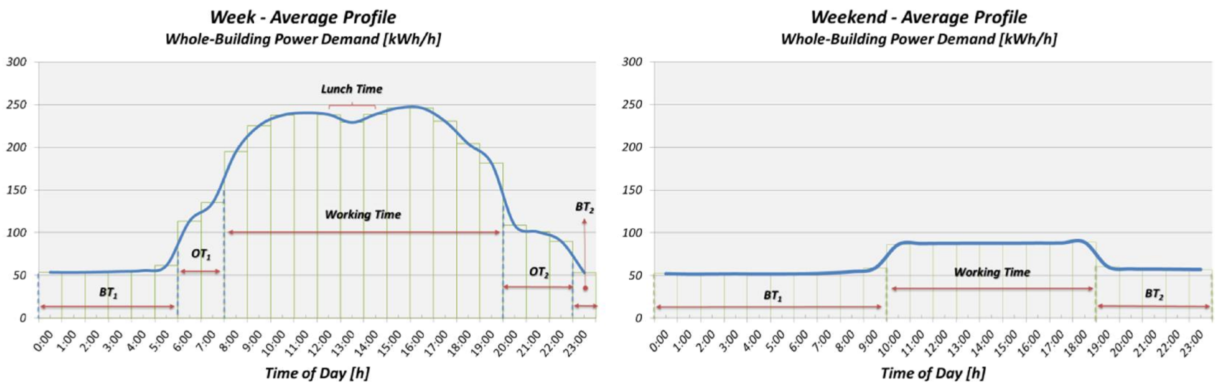

Figure 5: Electrical daily load profile for week and weekend days respectively.

According to profiles seen in Figure 5, some different periods can be easily recognizable during a working day. They are:

1. Working time (WT): period corresponding to the biggest part of the day that also comprises an "intermediate" break time period (coffee, lunch, etc.). It is normally defined by the company and corresponds to the "nominal" hours' number that an employer must be as minimum at his working place. This period is also use for defining operation time of building services (heating, cooling, ventilation, etc.).

2. Over Time (OT_1 & OT_2): Period that employers usually take for advancing work or recovering lost time. It corresponds to a transition period between base time and working time and some applications 'usage can be allowed.

3. Base Time (BT_1 & BT_2): Period corresponding to non-occupancy when building is closed. At some zones lighting and appliances still work at stand by, security or "base" level consumption.

The considerable amount of individual consumptions (undetermined at this level) which take part of whole-building electrical power demand do not allow identifying the causes of the shape or the order of magnitude of the profiles and only some presumption about occupancy and services operation time can be made for trying to explain this issue.

A complete description of BEMS definition and monitoring data related to subsystem measurements (lighting, appliances, HVAC system, etc.) are needed to reveal this "mystery". These aspects are out of the scope of this paper and should be performed in other phases of the building calibration process.

Description of Selected Model Responses

Model Response 1: Average daily profile

Model response 1 is an average hourly profile (over one year) obtained from metered data corresponding to reference building and to year 2009.

To obtain this response, the first step was dividing the data profile by days and arranging it as a sort of matrix of 365 (days) rows by 24 (hours) columns. Then, by means of a visual recognition and helped by the official calendar of 2009, the data set was splited in two: “weekdays” and “weekend and holidays”. After this, both sets were averaged hour by hour obtaining two average daily profiles of 24 hours each.

The outcome of the whole process is a yearly profile (8760 hrs) which comprises: one weekday and weekend daily profile repeated as many times as working days, weekend days and holidays contains the calendar year 2009. For this building, operating schedule for weekends is the same as for holidays.

This solution has been chosen for being considered as the simplest solution that could be obtained and also one of the most used techniques used by practitioners (averaging profiles).

It is expected to have a good agreement in terms of monthly and annual base time because it corresponds to an averaged curve. In terms of hourly indexes MBE should have a near zero value but for $CV(RMSE)$ is not previewed.

Model Response 2: Profile for the same building but corresponding to another year

Model response 2 is built by using a profile corresponding to another year and assuming that corresponds to the year in question. For this purpose is used a whole-year profile for year 2008 as if applicable to year 2009. In order to avoid synchronization mistakes, the only arrangement done was:

- January 1st and 2nd were left unchanged (holidays)
- Since January 3rd (Saturday) to December 30th (Wednesday), the corresponding assigned profile days for year 2008 were January 5rd (Saturday) to December 30th (Wednesday).
- For the remaining December 31st (Thursdays), was filled by January 3rd 2008.

Then to each reading of the yearly profiles was assigned time and date values corresponding to calendar 2009.

This solution has been also chosen for being easy to get (in this exercise). In reality, getting this solution would be equivalent to model perfectly the building and its HVAC systems which is impossible.

Assuming that the operation of the building (control parameters) did not change, this profile (in the case of being obtained by a formal procedure) would represent to having calibrated a model with a different weather file but corresponding to the same climate (same city). So, the source of uncertainty comes mainly from this limitation.

Similarities and Differences between both Model Responses

In the frame of the ECBCS Annex 53 project [9], six family factors which impact on the overall building energy use were defined. Over the basis of this definition, the comparison of both model responses is done.

Table 3 – Level of detail reflected by model response 1 and 2

Family Factor	Model Response 1	Model Response 2
Climate	Detailed (as it is)	Not exactly the corresponding profile, but the same climate
Envelope	Detailed (as it is)	Detailed (as it is)
HVAC Equipment	Detailed (as it is)	Detailed (as it is)
Operation and Maintenance	Simplified cooling plant operation	Detailed (as it is)
Occupants Behavior	Simplified. Fixed over the whole year	Detailed (as it is)
Indoor Environmental Conditions	Detailed (as it is)	Detailed (as it is)

For the purpose of this analysis, statistical indexes should reflect better results for this model response 2 than for 1.

Results

Current Acceptance Criteria: Evaluating statistical indexes

Figure 6 and Table 4 show the summary of adequacy of both model responses.

Figure 6 - Recorded and predicted whole building electricity consumption (monthly base)

Table 4 shows the statistical indexes summary at annual, monthly and hourly level.

Table 4 - Statistical indexes summary

Index	Model Response 1	Model Response 2	Reference
$MBE_{year,month,hourly}$	-0.01%	-1.8%	<±5% (Waltz, 2000)
$CV(RMSE)_{month}$	6.3%	6.8%	<±15% (ASHRAE, 14)
$CV(RMSE)_{hourly}$	18.2%	25.7%	<±30% (ASHRAE, 14)

Both models are able to predict annual and monthly electrical energy use and hourly power demand within the tolerance range listed in Table 4.

For model response 1 discrepancy comes from the fact of averaging profile which induces an underestimation of hourly consumption for the hottest months of the year (see June, July and August in Figure 6, left).

In the case of model response 2 the situation is different and the differences can be related to the incidence of weather conditions which are different than recorded data.

Finally, according to current criteria, is possible to conclude that ***both models have been succesfully calibrated!***

However, still some questions come to mind:

Now, we are sure about the accuracy reached when representing actual building energy performance, but; can we be sure about the accuracy when representing another different situation? Next sections disccuss this issue in details.

Evaluating Model accuracy and its capability of measuring a new situation

Because, to evaluate proximity (point to point) of yearly two lists of 8760 values corresponds to a cumbersome analysis, it is needed to apply some complementary techniques such as statistical and visualization techniques.

A curious aspect, which do not only occur when analyzing hourly results (Table 4), is the fact of obtaining more accurate results for the simple model (*model response 1*) instead of the detailed one (*model response 2*). In this part of the analysis is intended to find an explanation to this issue and also identify the capabilities and limitations of the information provided by statistical indexes. Figure 7 plots a comparison point by point between recorded and predicted data obtained from both models.

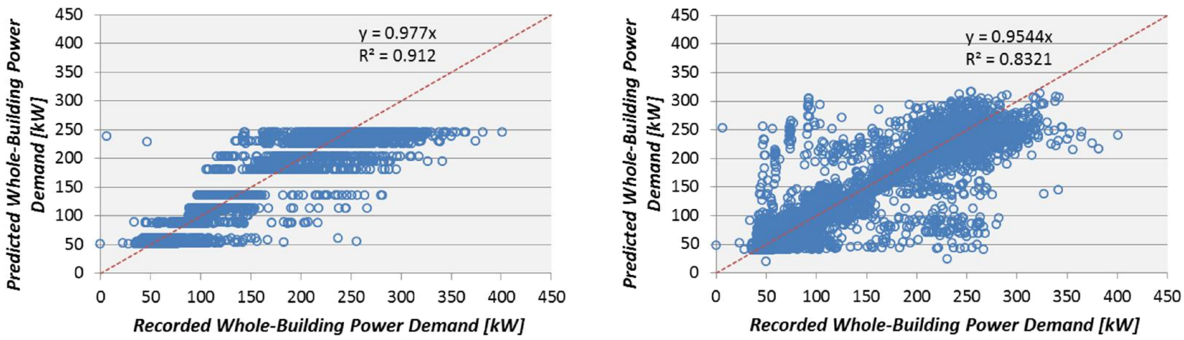

Figure 7 - Predicted versus recorded hourly power demand (Model Response 1 – left side; Model Response 2 – right side)

First of all, both graphs show a large dispersion between predicted and recorded data, even taking into account the good coeficient of determination (R^2) obtained by both models, 0.91 and 0.83 respectively. The position of the points (above and under the red line) explain the "compensation error effect" that produced the low values obtained when MBE index was evaluated (for all the time scales). $CV(RMSE)$ index in annual and monthly base did not show big values mainly due to the capability of both models of predicting consumption in periods of time which do not change their conditions significantly from one scenario to another or from one year to another.

Where considerable differences were found was when evaluating $CV(RMSE)$ in hourly time scale. For the case of *model response 1* (which was built by means of averaged profiles) it makes sense because at some extreme conditions electrical consumption values can increase considerably, however in the case of *model response 2* this issue is intriguing because it is suposesly to be the most accurate model wich could be obtained.

The reason about this last issue is none other than the "desynchronization" between both profiles. It is impossible to replicate the same conditions for two equivalent days even if they correspond to the same date (in the case of two different years). This fact demonstrates that when evaluating calibration accuracy at small time scales (or scales where conditions are very variable) is not appropriate to make an analysis by comparing the proximity of two time series (point to point) but must be carry out another method that takes into account the dynamic behavior of the power demand, regardless its evolution over time.

Figure 8 shows a bin analysis made over hourly consumption data. From a probabilistic point of view, it provides a distribution of power demand levels along the year. Predicted and recorded consumptions are plotted in terms of relative frequency and cumulated relative frequency.

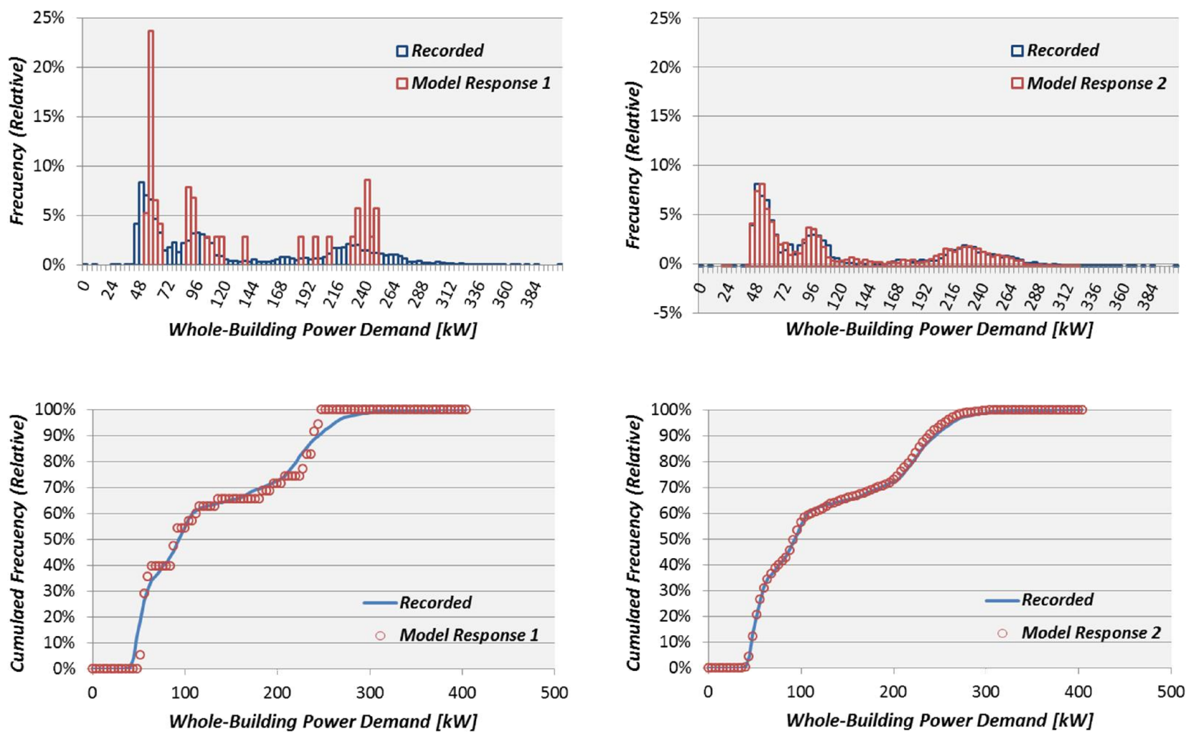

Figure 8 - Relative and cumulated frequency comparison between recorded and predicted data (hourly base)

Now, differences between recorded and predicted data and the quality of both models responses are more evident. Model response 1 only providing 48 different hourly consumption values (24 for weekdays and 24 for weekends) spread all over the year is perhaps not enough for representing the real dynamic behavior of the electrical consumption.

On the other hand, model response 2 represents an incredibly accurate situation even taking into account the values obtained by evaluating the current criteria.

This approach certainly represents an appropriate way to evaluate accuracy in calibration procedures. Although until now, it has only provided visual comparison of two electrical profiles, it is imperative to define one or more indexes to quantify proximity between predicted and recorded data without using Euclidean distances.

Proposed Complementary Approach

The analysis carried out in the previous section highlighted the limitations of the current acceptance criteria and the necessity of going to more detailed timescales when determining accuracy and reliability of simulated data. In this section some complementary analyses are proposed to check reliability of the information provided by statistical indexes.

Operative hours

The comparison of corresponding hours to each day type and daily period, between simulated and recorded profiles is crucial to verify that the simulation was done according to reality. For example, year 2009 had in total 8760 hours (non leap year) divided in 5976 hours per weekday (249 days) and 2784 hours per weekend day (116 days).

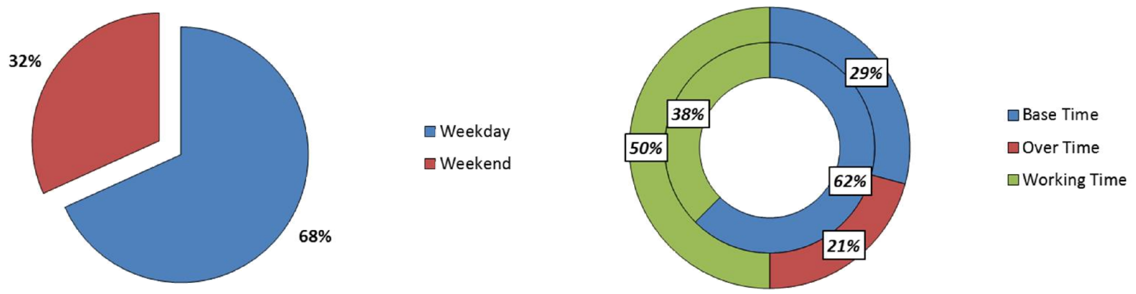

Figure 9 – Annual operative time disaggregation according to daily period and day type. Corresponding to year 2009.

This issue was previewed when creating response profiles, so in this exercise, differences between simulated and recorded data come from modeling discrepancies and not from simulation ones.

Summary of hourly power demand by means of statistical plots

In real building operation, BEMS controls and allows the electrical use according to permanent daily periods (defined mainly according to occupancy). The occupants' behavior and their decisions, the "calendar", the effect of meteorological variables over thermal loads and over some BEMS decisions as well as the installed capacities of lighting, appliances and equipment determine the electrical power demand profile in terms of shape and order of magnitude.

Although this profile changes from one year to another or from one scenario to another there is a clear global behavior that can be revealed using the proper approach and tools.

Figure 10 shows a probabilistic approach plotting a (discrete) relative and its corresponding cumulated distribution for 3 year recorded data corresponding to DM28 building.

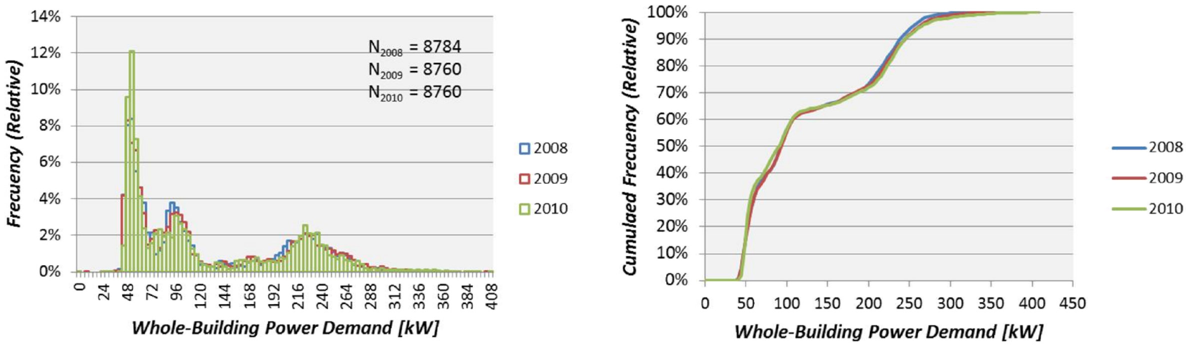

Figure 10 - DM28 relative frequency and cumulated frequency for whole building power demand. Recorded data for year 2008, 2009 and 2010.

A good agreement and a repeatable behavior are observed in both graphs plotted in Figure 10. Addressing the problem from a probabilistic point of view allows to identify the frequency of each event (consumption level) occurring during the year and also a way to evaluate calibration accuracy between two series of data.

In order to refine the results, this approach can be extended to different subsets of data grouped by: day type (week, weekends, holidays, etc.), daily periods (non-occupancy, working hours, etc.) and even could be associated to meteorological variables (temperature, humidity, etc.), in case of having reliable data.

Conclusions

In this paper, current criteria used to assess accuracy in building calibration procedures has been tested by means of two “simplified” models showing its strengths and weakness.

“Current criteria is necessary but not sufficient”

What current criteria do is: to compare predicted to recorded data point to point (calculating Euclidean distances) and estimating an average value which must be in accordance with a defined tolerance. This approach is appropriated when data integrated over a large period of time is analyzed. Annual and monthly consumption fit very well to be assessed by actual approach.

If a more detailed analysis is required another type of analysis is needed. Bin analysis has shown to be appropriate.

In the presence of a real calibration procedure, this same exercise (proposing a possible solution and evaluate its adequacy) can be used to determine the minimum requirements the model must fulfill in terms of accuracy. It would allow realizing whether the ultimate goal of the calibrated simulation model is reachable or not.

Finally, the building calibration problem will always remain an underdetermined mathematical problem and a unique solution is impossible to find, however the fact of having achieved replicating in a correct way the dynamic behavior of electrical consumption, suggests that the found solution is not far from the real one.

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CONSUMPTION BENCHMARKING: DIFERENCES OF CLASSIFICATION OF COMMERCIAL BUILDINGS FROM ACTUAL CONSUMPTIONS AND OCCUPATION DATA

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Abstract

The RTQ-C, Technical Regulation of Energy Efficiency of Commercial, Service and Public Buildings was released in Brazil in 2009. However, four years after its implementation, there is scarce data to allow the evaluation of the prescriptive and simulation methods of the Regulation relating the building classification and its energy consumption. Thus, this paper aims to analyse the classification differences that may occur in the application of the simulation and prescriptive methods proposed by the Regulation. In order to achieve that, a real building was studied, which in 2011 received the "PBE Edifica" (Brazilian Labelling Program) label of Commercial, Public and Services buildings of the 2009 version of RTQ-C´s prescriptive method. The paper is therefore divided into two parts, it discusses at first, differences obtained in the building classification by computer simulation, proposed by RTQ-C, as a function of the users schedules assumed. For this purpose, the classifications achieved by three different schedules were compared: (a) a schedule defined in the design stage by the air conditioning system designer; (b) a schedule pre-defined by the simulation program for the building typology; (c) a schedule developed from the building occupancy data, in other words, the timetable of the workers. In the second part, the prescriptive method of the 2010 version of the Regulation was applied and the results were compared with the simulation ones. The influence of the envelope pre-requirements on the energy consumption was considered. The distinctions presented on the energy consumption as a function of varying schedules were significant in the final classification by RTQ-C, while when varying the prerequisites values, minimal differences in the building electric energy consumption were obtained. This paper indicates that decisions made by the professional responsible for the simulation have an extreme importance, as established timetables and routine uses can impact on the forecast of consumption in new buildings.

Introduction

According to Geller [1], a sustainable future regarding the use of energy is possible through more efficient usage processes. According to the author, with improved efficiency, there would be a reduction in the increase of energy consumption and, consequently, it would be possible to obtain shrinkage in the demand for investment in new generation sources, as well as significant improvement in supply services to households and poorer nations.

In referring to the more efficient use of energy, the buildings can make a substantial contribution, since they account for a significant portion of the consumption of electricity and the production of construction waste, besides being major consumers of raw materials. According to the National Energy Balance - BEN [2] the country's energetic demand shows a considerable concentration in consumption linked to building stock, mainly in commercial, residential and public sectors, which together represent 46.70% of total consumption.

In countries whose energy efficiency regulations already show consolidated or on consolidation phase, a significant parameter to be collected is the power consumption according to the types of buildings. This database is called benchmarking, which are commonly known as a continuous and systematic process that allows the comparison of the performances of the institutions and its functions. From this data collection, it is possible to propose new criteria for construction and to review the existing ones, in addition to improve the management of buildings of different performances.

The purpose of creating the benchmarking is to establish indicators of energy consumption for commercial buildings in Brazil, with technically feasible methodology to collect consumption data and parameters of interference in buildings energy consumption. Thereby, it would create a database of average consumption of commercial buildings, allowing the energy performance to be correlated with architectural parameters, usage and systems installed in the edifice.

There are 3 levels of benchmarking:

1. Simple Benchmarking – consumption per square meter for a specified typology, with climatic correction;

2. Benchmarking with correction – benchmarking with corrections, more detailed, usage intensity, final especial uses;

3. Tailored Benchmarking – benchmarking tailored for the performance of a building, comparing their potential for energy efficiency, based in an energy audit and the calculated potential of improvement.

This work would complement the development of the energetic efficiency in buildings, which has started in February 2009 when it was published in Brazil by the Brazil's National Institute of Metrology, Standardization and Industrial Quality – Inmetro, the Energy Efficiency Rating Technical Quality Regulations for Commercial, Service and Public Buildings – RTQ-C [3]. The same was revised on September 17, 2010 (Ordinance No. 372 INMETRO) and in 2012 received a supplementary ordinance (Ordinance 17 of January 16, 2012). This Regulation aims to *"create conditions for labeling the level of energy efficiency of commercial, services and public buildings."* [3].

The energy efficiency label can be provided to the entire edifice or part of it and may be obtained by prescriptive or simulation methods. The former uses prerequisites and predictive equations that will result in parameters to achieve certain values for each rating level. The latter uses a software simulation of thermal energy, which necessarily models the hourly variations of all thermal loads of the building divided into multi zones considering the effects of thermal inertia and, moreover, is capable of estimating the bioclimatic strategies adopted in the design.

According to Carlo e Lamberts [4], the simulation method is the most complete for any analysis of the thermal energy performance of a building, providing flexibility in options aimed at the rationalization of energy consumption, which includes the design process. Mendes *et al*. [5] claims that with simulation programs, it is possible to evaluate the thermal and energy performance of edifices for different design alternatives, be they architectural design options, building components, lighting or air conditioning systems. Therefore, with the computer simulation, one can estimate the energy consumption, its cost and the environmental impacts caused by the different design alternatives before its execution or lead to improvements in buildings already consolidated.

The job of predicting consumption of buildings complements the work of their classification according to their level of energy efficiency. This work requires a survey of the building as described by Wang *et al*.[6] and Fumo et al. [7], who claim that the forecast energy consumption of the edifice is a complicated task since it requires a survey of the characteristics of the construction as the components of the envelope, its lighting systems, HVAC and hours of use of the building. Moreover, they allege that the dynamic behavior of weather conditions, the implementation and impact of building construction characteristics require the use of computer simulation to facilitate its design and operation and thus, provide a better performance of an edifice. The authors also point out that the deviations between the predicted building energy consumption and the actual one can be attributed to four uncertainties: the accuracy of the construction of the simulation model, the accuracy of the input parameters that describe the building components and systems, the actual weather conditions, and the actual use and operation of the building. An estimate of the uncertainty of each factor is important for improving the performance of simulation models and it helps the simulator and the client to have a better evaluation of the building's consumption.

With this, the next step in improving the development of energy efficiency in Brazil is to create these consumption benchmarks, to demonstrate the real gains in buildings with investments made in the certification process. The first work that is under development concerns banking agencies, in which data were obtained from public and private banks in all regions of the country, whose usage and occupation show similar patterns. For this article, the case study used was a call center of a bank, but that can not be compared with the benchmarking in development by having different styles of use and occupation. With this study, it will be possible to verify that this two variables have an important impact in the final energy consumption of the building, so the collection of this data is relevant for the future development of a benchmark for this typology.

Objective

The main purpose of this article is to analyze the differences in classification according to the simulation method proposed in RTQ-C (Technical Regulation of Energy Efficiency of Commercial, Service and Public Buildings) of an existing building already labeled in 2011 by PBE Edifica - Brazilian Labeling Program, depending on the varying patterns of usage and occupation.

Method

This study evaluates the influence of the parameters for use and occupation and prerequisites on the energy consumption of a commercial building. This analysis will be conducted in two phases: evaluation of the influence of parameters for usage and occupation on the edifice energy consumption and their classification by the method of simulating by the PBE Edifica label; and comparison of final classification of the building prescriptive and simulation method. This methodology will be detailed below.

Definition of a base building

The chosen building for analysis was a call center located in the city of Belo Horizonte with an area of 5.976,00 m², 02 floors and a parking lot on the roof. In 2011, the building received the Brazil's National Electricity Conservation Label – ENCE in the design phase in accordance with the regulation published in 2009. Performance envelope, the artificial lighting system and air conditioning were evaluated and the building also received a bonus for saving water. The classification obtained by the prescriptive method, reached the level A[1], with a final score of 5.60 points (Envelope - A, lighting - B, air conditioning - A and 1 bonus point for water savings). The image of the building and received tag are shown in Figures 1 and 2 below.

[1] This rating ranges from A (most efficient) to E (least efficient), and in order to receive the level A, the building must obtain a score above 4.50 points.

Figure 1 – Finished Building Picture

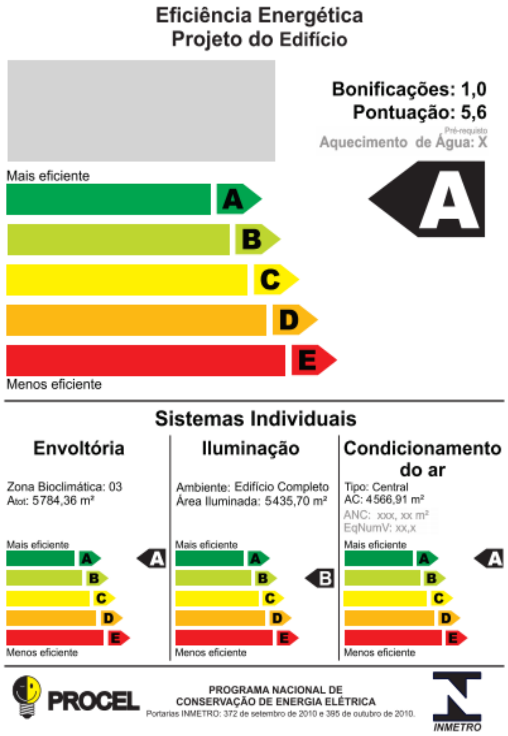


Figure 2 - ENCE of Design of a Building

Analysis of the characteristics of the building

The base building consists of 02 floors subdivided with partitions from floor to ceiling. On the first floor, there is the reception, bathrooms, meeting rooms, training rooms, multipurpose rooms, maintenance, treatment and machines room. On the second floor, there are treatment rooms, offices, bathrooms, machines room and storehouse. The building was simulated in Energy Plus, version 7.2 and was divided into 16 thermal zones, there being eleven zones on the first floor and five zones on the second. The weather files used in the simulations was TRY (*Typical Reference Year*) of the city of Belo Horizonte, developed by Pereira [8], which is based on data of the conventional weather station of INMET/5º DISMEA.

The openings of the building are located in the north and south facades and have a total area of 165 m². The glass used in these openings was the Cool Lite 114 AI 4mm and its characteristics are shown in the Table 1 below.

Table 1 – Glass characteristics

Solar Transmittance at Normal Incidence	11%	**Back Site Visible Reflectance at Normal Incidence**	26%
Front Site Solar Reflectance at Normal Incidence	22%	**Shading coefficient**	0,21
Back Site Solar Reflectance at Normal Incidence	36%	**Infrared Transmittance at Normal Incidence**	73%
Thermal Transmittance (W/m^{2}K)	2,89	**Solar Factor**	18%
Visible Transmittance at Normal Incidence	8%	**Heat Gain (W/m^2)**	164
Front Site Visible Reflectance at Normal Incidence	19%		

The walls and roofs were defined according to the existing on site. The thermal properties of the materials used, such as thermal conductivity, density, specific heat and thermal resistance, were obtained in NBR 15.220 parts 2 and 3 [9], [10]. For obtaining the walls and roofs absorptances, measurements of the used materials were taken using the spectrophotometer ALTA – Refletance Spectrometer. It is noteworthy that the average values of transmittance and absorptances of walls and roofs met the prerequisites set by RTQ-C to the envelope for classification level A. Table 2 lists the input data used to compose the walls and roofs and the average absorptances used.

Table 2 – Characteristics of the materials used in computer simulation

	Descrição	Area (m²)	U (W/m²K)	α medium
Roof	Concrete floor + Rockwoll insulation (Geotextil) + Rockwoll insulation + Cellular concrete slab + air-chamber + gypsum liner – total thickness: 22 cm	2935,40	0,85	0,20
Wall	Plaster + masonry of ceramic blocks + plaster = total thickness: 22cm	4813,32	2,54	0,28

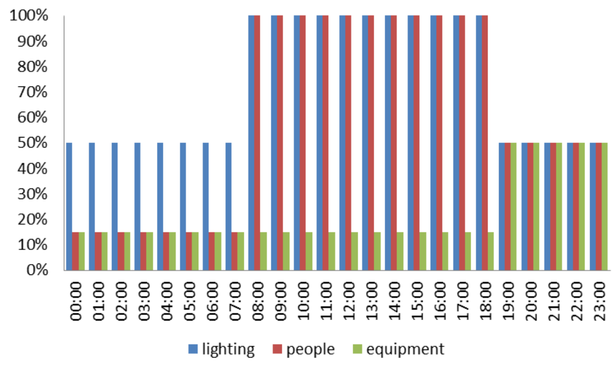
The internal heat load of the building is an important factor in energy consumption since the building is a call center where 1,430 people work in various shifts. The business hours of the edifice are 24 hours a day, 7 days a week. The lighting system consists of lighting fixtures with lamps of 14W, 20W, 28W and 36W, with a total installed capacity of 63.300W. Computers, audiovisual equipment and lift characterize existing electrical equipment at the site, with total installed capacity of 136,042 W.

The air conditioning system installed in the bank is the central type, with chiller comprises scroll type compressor and condensing by entrained air. The chiller capacity is 82.1 TR, with COP of 2.82 and 3.99 IPLV. The cooling set point temperature is 24ºC and 18ºC is warming.

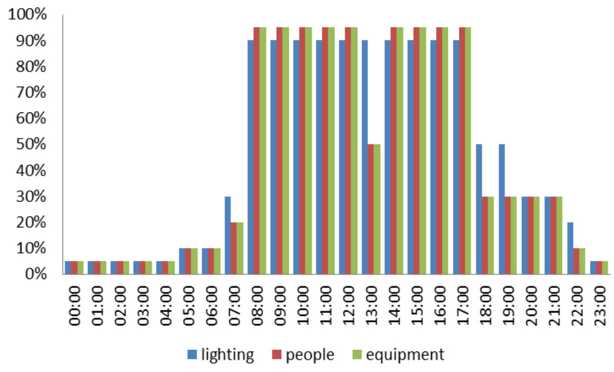
The schedule of the air conditioner sets its operation for 24 hour a day and air conditioning takes place according to the temperature set point established by the designers and also with the use of the rooms (patterns provided in Figure 3) since the building runs continuously.

With respect to the usage of the building, lighting, equipment and people, 3 simulations were made:

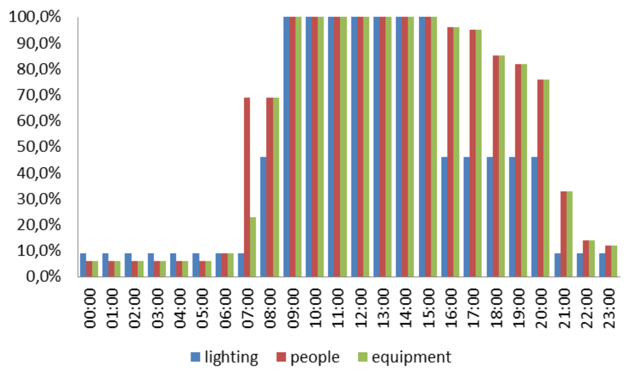
- First – designer's database: a standard is determined by the designer of the air conditioning for the use of the building – designer's database (Figure 3-a);
- Second – data from the simulation program: it was used a schedule preset by the simulation program to the typology analysis (Figure 3-b);
- Third – data collected: it was used the schedule developed from the database of employee's work, estimating according to the activity of the employees, the hours of equipment and lightning system usage (Figure 3-c). The occupancy data were therefore provided by the building management. Lightning and equipment usage were estimated in relation to the occupation of the building.



(a)



(b)



(c)

Figure 3 - Standard occupancy of the building (a) schedule provided by the designer, (b) schedule provided by Energy Plus, (c) schedule developed from occupancy data provided by the company and estimated use of equipment and lighting from occupation

These three phases were chosen because the usage and occupation data used by the designer of the air conditioning was different from the ones used in the schedule preset in the simulation program and both of them were different from de actual occupation. Thus, this work wants to investigate what data is closest to the actual consumption of the building.

PBE Edifica Rating by the Simulation Method

According to RTQ-C, in the simulation method, one should use a thermal energy program simulation that models the time-variations of all the thermal loads of the building divided into multi zones, considering the effects of thermal inertia and the capacity of simulating the bioclimatic strategies adopted in the design. The reports of energy use are used for analysis and for establishing the rating level achieved.

The evaluation is done by comparing the actual building, according to the proposed project, with another reference set from the prerequisites and classification systems from the prescriptive method. This reference model must have the same characteristics of the real one as shape of the building, number of thermal zones, patterns of use and occupation and internal loads of equipment. The parameters that are changed to set the limits are opening percentage of the total facade (PAFt), thermal transmittance prerequisites of walls and roofs (Upar and Ucob) and absorptances of walls and roofs (αpar, αcob). Thus, in accordance with the requirements of Conformity Assessment for Energy Efficient Buildings, INMETRO Decree 50 of 2013 [11], it is determined that the annual energy consumption of the reference building should be compared with the actual building and this should be analyzed according to the level of energy efficiency to be achieved. The power consumption of the proposed building must be equal or lesser than the consumption of that reference certain level of classification.

The parameters used in the simulated models are in accordance with the specifications of the RTQ-C [3]. Therefore, there are the prerequisites of the envelope (Ucob, Upar, αpar, αcob) and their limits for each level; densities of installed power lighting system according to the main activity of the building, office activities in this case; and the efficiencies of air conditioning depending on the type of existing system. Items occupancy and equipment are equal in both the actual building as the reference models. These values are shown in Table 3.

Table 3 - Characteristics of the simulated models - Real Building and Building limits for A, B, C and D

Parameter	Real Building	Level A	Level B	Level C	Level D
PAFt	0,06	0,18	0,31	0,44	0,57
Upar (W/m²k)	2,54	3,70	3,70	3,70	3,70
Ucob (W/m²k)	0,80	1,00	1,50	2,00	2,00
αpar	0,20	0,5	0,5	0,5	0,5
αcob	0,28	0,5	0,5	0,5	0,5
Equipment (W/m²)	22,76	22,76	22,76	22,76	22,76
Occupation (people/m²)	0,11	0,11	0,11	0,11	0,11
Lighting – Ofice(W/m²)	10,77	9,7	11,2	12,6	14,1
Minimum efficiency of the air conditioning system (COP, W/W)	2,82	2,802	2,802	2,80	2,70
Temp. set point (^{o}C)	18 e 24	18 e 24	18 e 24	18 e 24	18 e 24

The reference models were simulated for all rating levels in order to enable the evaluation of the difference in consumption from one level to another. Furthermore, for comparison and validation of simulation data, information about consumption of electricity of the actual building supplied by its administrators from December 2011 to November 2012 was used.

Analysis of Results

Consumption of the building

In early tests, a comparison of the annual energy consumption of the building was made, performed by computer simulation with its actual consumption. The data of real consumption of the edifice were provided by its administrators and are related to the months between December 2011 and November 2012, and are shown in Figure 5.

Through computer simulation using the actual routine occupation, which is considered closest to the actual behavior of the building, it was found that approximately 9% of its total consumption is related to lighting, 9% refers to pumps, 26% are on equipment and 56% is related to the air conditioning system, as seen in Figure 4. It is noted that the building analyzed consumes on average 9% more for air conditioning and 13% less than the artificial lighting consumption established typical for a standard commercial building presented by Procel [12].

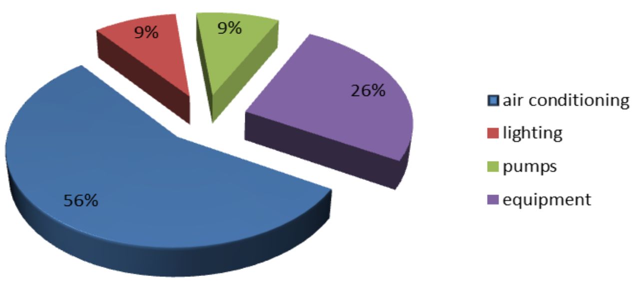
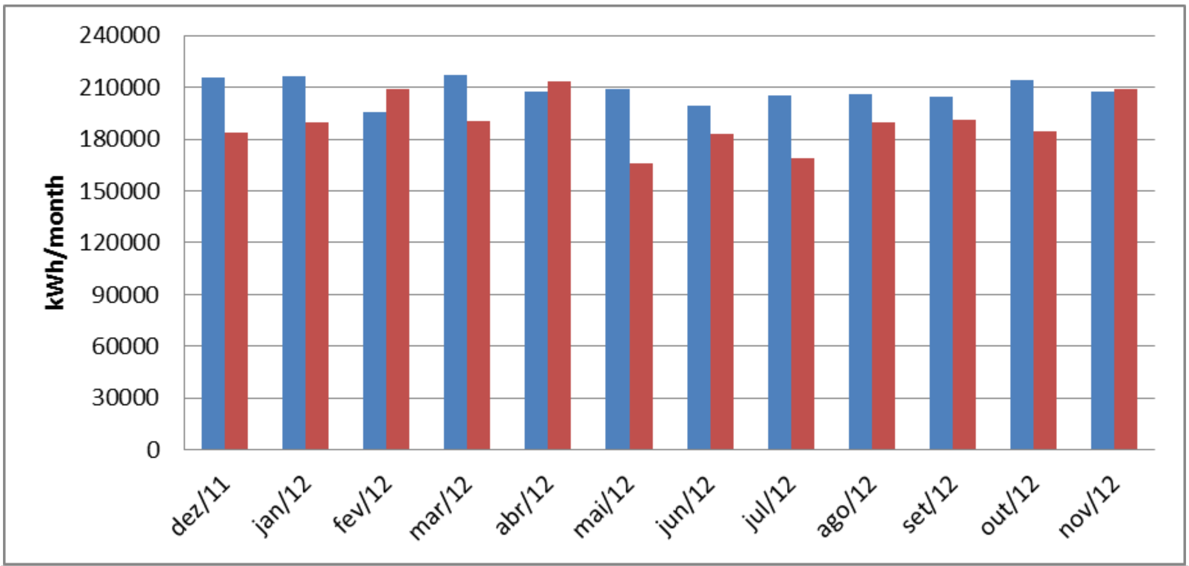


Figure 4 - Call center`s disaggregated consumption

As show in the Figure 4, the percentage of the air conditioning system in this building represents more than half of the consumption. The definition of the routine of this equipment in the simulation will influence directly in the forecast of the building consumption provided by the software.

Moreover, it was also compared the power consumption shown by the simulation obtained from the occupation data provided with the consumption presented by the electricity bills of the building. The differences ranged from -6.60% in February to over 20.67% in May, as can be seen in Figure 5. The average annual consumption variation between the simulated and actual consumption showed an overestimation of 8.91% of the simulated value in relation to the actual one. This difference may have been caused by differences in routine assumed, by the use of lighting, by the air conditioning of some environments of the building and even climatic differences between the TRY year and the actual one.



	dez/11	jan/12	fev/12	mar/12	abr/12	mai/12	jun/12	jul/12	ago/12	set/12	out/12	nov/12
collected	215732	216663	195682	217015	207329	209124	199475	205293	206030	204389	214479	207783
actual	183400	189700	208600	190400	213500	165900	182700	168700	189700	191100	184100	208600
difference %	14,99%	12,44%	-6,60%	12,26%	-2,98%	20,67%	8,41%	17,82%	7,93%	6,50%	14,16%	-0,39%
KWh/m²/month collected	36,10	36,26	32,74	36,31	34,69	34,99	33,38	34,35	34,48	34,20	35,89	34,77
KWh/m²/month actual	30,69	31,74	34,91	31,86	35,73	27,76	30,57	28,23	31,74	31,98	30,81	34,91

Figure 5 - Monthly consumption of the actual and simulated building

By analyzing the routine use of the building shown in Figure 3, one can also verify that the usage data used by the designer of the air conditioning (a) and data from the schedule submitted by the simulation program (b) tend to overestimate by about 67% the time of use of equipment, lighting system and air conditioning from 19:00 to 6:00 in the morning compared to the actual data from the building (c).

Assessment of consumption in relation to the usage

In 2011 the building was submitted to OI3E (Inspection Office of Energy Efficiency in Buildings CERTI Foundation) for the issuance of project label according to the prescriptive method. The building reached the overall "A" rating. For this work, the label has been updated to the 2010 regulations and also evaluated the building by the method of simulation, considering all the constraints specified by RTQ-C, as shown in Table 3.

In the first test, it was used a simulation routine provided by the designers, as shown in Figure 3a. The classification achieved by the construction according to RTQ-C was level B, as can be seen in Figure 6 and thus, there would be consumption 19.45% higher than the actual building. In this case, the difference between A-level and other levels ranging from 2.31% (the rating from B to A) to 10.91% (D to A).

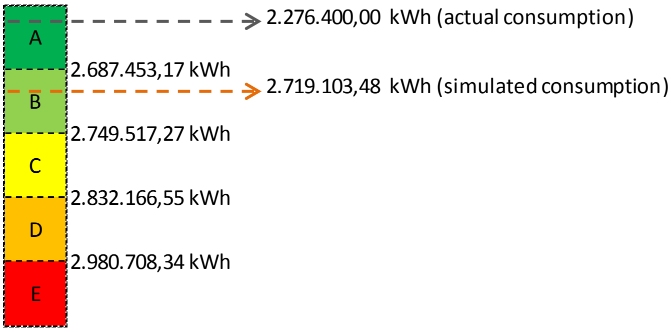


Figure 6 - Classification of the building according to the RTQ-C - simulation method with established routine by designers

In the second test, it was used the actual data routinely in the building. The classification was achieved level A, as can be seen in Figure 7. What can also be seen in this simulation is the difference in consumption between the different levels in relation to maximum ("A"), considered the most efficient. The results show small differences and these varied from 1.55% B to A, 4.0% of C to A and from D to A, 12.16%. The difference in consumption between the actual and simulated building consumption data was raised to 8.91%, as shown previously in Figure 5.

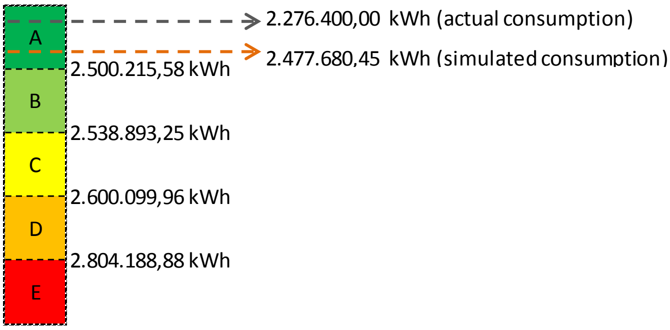


Figure 7 - Classification of the building according to the RTQ-C - simulation method with routine occupation collected on site

In the third test, the routine is replaced by the routine of an existing standard office building as an example the Energy Plus program. Thus, the energy consumption of the building decreases compared to the simulation of the first test, but retain the classification in RTQ-C level as B, as can be seen in Figure 8. The consumption of the building has overestimated its value at 10.29% compared to the actual building. Since the difference between the levels in this case was lower than in the previous case where the routine had been established by the designers, but still preserved with minor differences between one level and another.

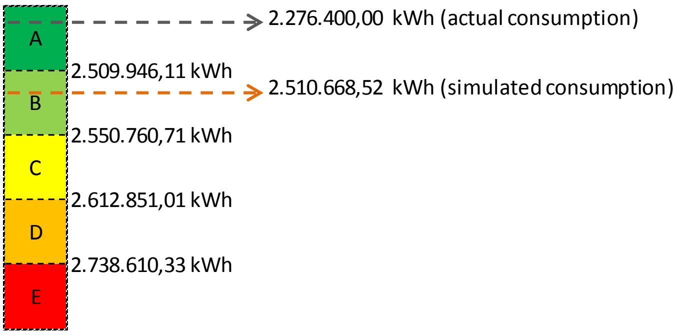


Figure 8 - Classification of the building according to the RTQ-C - simulation method with standard routine of Energy Plus

Conclusions

In this work, the results of the energy consumption of a call center building were compared from occupancy data and electricity bills provided by administrators of the same, with the consumption data estimated through computer simulation. Using data from the working schedules of the employees to estimate the routine use, we obtained a difference between the simulated consumption and actual consumption of the building of 8.91%. This variation is probably caused by possible differences in user behavior and differences of the climate data file against the behavior of the weather in the year of data collection of energy consumption.

On the other hand, when we assessed the classification of the building by the simulation method of the RTQ – C, the building got the same final grade obtained by the prescriptive method using the 2010 version of the Rules. Obtained level “A” in the global tag, which indicates a good correlation between the two methods in this case. From this first analysis , changes were made in the routine use of the building from the schedule provided by the designer of the air conditioning and the schedule provided by the simulation program to study the typology in case. These routines have caused consumption to increase by 19.45% in the case of the routine provided by the designer of the air conditioning and 10.29 % with the routine provided by the simulation program for that typology. These differences led to building consumer to obtain an overall “B” level, which clearly demonstrates the importance of routines undertaken by the simulator to obtain the classification of the edifice.

Regarding the steps between levels for classification by the RTQ-C, using the reference models in the three cases studied, the consumption values obtained were close to each other. It is believed that these values showed minimal differences between one level and another due to its large internal load of equipment installed in the building. However, here it is indicated in later simulations to check the adequacy of the steps found for building high-density internal load.

With this study, we can conclude that the role of the professional that will simulate the building and check the consumption of new buildings is extremely important because with the choice of a usage routine closer to the actual building, he can envision consumption significantly closer to the reality of the future building. Furthermore, by proving the consumption, he will be able to potentiate the reduction of consumption from actual benchmarks and thus, have a continuous improvement of the building, valuing and promoting a differential in property.

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Understanding Energy Efficiency Opportunities in Commercial Buildings Using Calibrated Whole Building Simulations

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Abstract

Accurate information on electricity consumption by end use by building segment is critical in planning, implementing and evaluating initiatives to improve energy use in commercial buildings and institutional. In order to understand Demand Side Management opportunities in the commercial and SUCH sector in British Columbia, DOE 2.1 models of 124 commercial and institutional buildings were built. The main data source was detailed on-site audits undertaken using trained engineering field staff. Complete data were collected on building geometry, shading, building envelope, heating, ventilation, air conditioning, domestic hot water, refrigeration, cooking equipment, process equipment, motors, office equipment, operating schedules, occupancy, fuel types and fuel accounts. This engineering modeling was used to characterize buildings, estimate end use consumption and gain insight into potential areas for further energy savings. The information provides annual end-use consumption per square foot for electricity and natural gas, based on normal weather and full occupancy for eleven building segments for ten end-uses. Several conclusions are worth noting. First, average total consumption per square foot varies substantially across building segments, from a low of 190 kWh per square metre per year for elementary schools to a high of 1,150 kWh per square metre per year for large grocery stores. Second, for most building segments, interior lighting is the most important electricity end use, while space heating is the most important natural gas end use. Third, the ratio of energy used to the ASHRAE 90.1 benchmark varied from 1.0 to 1.7. Fourth, the biggest energy savings opportunities for most segments include interior lighting and HVAC auxiliaries.

Introduction

Between 1990 and 2009, total energy consumption in British Columbia increased by 22%, reaching 1,264 PJ in 2009. For this time period, population grew by 36% and GDP rose by 61%, so that energy intensity fell by 10% per person and by 24% per dollar of real GDP. Growth in total energy use varied substantially depending on the sector. Again between 1990 and 2009, total energy consumption in British Columbia grew by 10% in industry, 32% in transportation, 32% in commercial, 27% in residential, but fell by 6% in agriculture. In 2009, the shares of total energy consumption British Columbia were 37.0% for industry, 27.5% for transportation, 12.4% for commercial, 12.6% for residential, 7.5% for agriculture and 2.6% for electric power generation own use [13].

Energy production and use in British Columbia is guided by the BC Energy Plan, released in 2009 by the Ministry of Energy, Mines and Petroleum Resources. The plan included four major sections covering Energy Conservation and Efficiency, Electricity, Alternative Energy, and Gas and Oil, and it provided a comprehensive set of 55 policy actions. Among its major policy actions, the BC Energy Plan had several related to energy conservation and energy efficiency. These included “set an ambitious conservation target to acquire 50 percent of BC Hydro’s incremental resource needs through conservation by 2020“ and “encourage utilities to pursue cost effective and competitive demand side management” [2].

In 2009, the commercial sector consumed about 12.4% of the total energy consumed in British Columbia, so that energy efficiency and energy conservation in the commercial sector are critical to meeting the Government of British Columbia’s overall energy efficiency and energy conservation objectives. The purpose of this study is to, first, analyze end use electricity and natural gas by various commercial buildings segments in 2009, and, second, identify potential energy efficiency and energy conservation opportunities. The study is based on comprehensive on-site building audits, survey data, weather data and energy use information used to inform DOE 2.1 models of 124 commercial buildings.

Data and Method

Method

Commercial buildings are major consumers of electricity and natural gas in most developed countries. Understanding end-use energy consumption in commercial buildings is critical in improving energy efficiency, reducing energy use, improving economic efficiency and reducing greenhouse gas emissions. A number of studies have examined various aspects of end-use energy consumption in commercial buildings. These studies include Bloyed et al. {1], Chan and Chow [2], Eto et al. [5], Global Energy Partners [6], Lam et al. [10], Mapp et al. [11], Oloffson et al. [14], O'Neil et al. [15], Sharp [18], Signor et al. [20], Tiedemann [21], Tiedemann and Sulyma [22], and Westphal [23]. These studies of commercial buildings have found that main uses of electricity in commercial buildings include space cooling, HVAC auxiliaries such as ventilation, interior lighting, exterior lighting, vertical transportation, refrigeration and miscellaneous equipment plug loads. These studies of commercial buildings have also found that main uses of natural gas in commercial buildings include space heating, water heating and cooking. The relative importance of various end uses varies substantially by building type, which suggests that energy end-use analysis should be conducted at the disaggregated building-type level.

The work for this study involved six main steps. (1) identify candidate buildings, (2) contact building operator and obtain authorization, (3) obtain utility data, (4) conduct on-site building review, (5) model energy use, and (6) provide customer report (Sheltair [19]). The objectives of the engineering modelling were to: (1) characterize the commercial building population, (2) estimate actual weather-normalized whole building energy consumption, (3) estimate hypothetical weather-normalized whole building energy consumption if the building just met the ASHRAE 90.1 standard, (4) calculate the ratio of actual weather-normalized energy consumption to this hypothetical weather-normalized energy consumption as measure of whole building energy efficiency, (5) estimate end-use energy consumption by segment, and (6) identify opportunities for energy efficiency improvements.

The main data source was on-site audits of 124 commercial facilities, conducted by trained engineering staff. The audits collected comprehensive information on building geometry, shading, building envelope, heating, ventilation, air conditioning, domestic hot water, refrigeration, cooking equipment, process equipment, motors, office equipment, operating and occupancy schedules, fuel types and fuel accounts. Detailed monthly fuel purchases were collected for electricity, natural gas and the central steam plant in Vancouver, Stem purchases were converted to their natural gas equivalent and merged with the natural gas purchases to reduce modelling complexity. For each building, a detailed input file was created merging on-site data, survey information, monitoring and verification metering profiles, billed energy use, weather data and occupancy.

Consumption and peak demand were first calculated using (a) actual weather and actual measures installed, so that the whole building models could be calibrated to actual electricity and natural gas loads. Actual weather and normal weather (Typical Meteorological Year) were obtained from the Environment Canada website. Calibration was undertaken so that modelled monthly energy consumption was within 5% of actual consumption. This typically involved adjusting hours of use for lighting and HVAC auxiliaries which were found to be the greatest sources of data error. A series of parametric runs was then undertaken using (b) normal weather and actual measures installed and (c) normal weather with measures installed which would just make the building complaint with ASHRAE 90.1. The results of the runs using normal weather and actual measures installed were combined with the on-site data on end-use saturations to produce end-use intensities. We distinguished between end-use intensity (EUI) which estimated end use consumption if that end use was present and unit energy consumption (UEC) which normalized for saturation levels, where the saturation rate if the share of buildings with that particular end use present. In other words,

$$UEC = EUI \cdot saturation\ rate.$$

Sample

Because of the anticipated high degree of variability within each building segment, the initial sampling plan was to stratify by building segment and then obtain at least ten completions in each of eleven building segments. It proved to be difficult to identify and recruit an appropriate mix of buildings to achieve these objectives. The final sample had these features: elementary schools, grocery stores/restaurants, high-rise residential and high-rise offices are over represented in the sample compared to the initial plan; secondary schools, hospitals, hotels/motels, and stand-alone retail were represented as per the initial sample plan; and extended care facilities, large malls and low rise offices were under represented in the sample compared to the initial plan. The following table summarizes the final sample by building segment and vintage.

Table 1. Sample by Building Segment and Vintage

Building Segment	No. of sites	1930-1959	1960-1989	1990-present
Elementary school	17	3	11	3
Secondary school	10	3	5	2
Extended care	5	0	5	0
Hospital	10	0	10	0
Grocery store/restaurant	13	1	4	8
Stand-alone retail	8	1	4	3
Large mall	4	0	4	0
Low-rise office	6	1	2	3
High-rise office	23	0	8	15
Motel/hotel	0	5	2	2
High-rise multi-unit residential	19	0	5	14
Total	124	14	60	50

Results

Building Characterization

Table 2 summarizes some key building characteristics of the study sample. The average floor area was 10,929 m^2. The largest average floor area was for the hospital segment while the smallest average floor area was for the elementary school segment.

Table 2. Building Characteristics

Building Segment	Average floor area (m^2)	Nominal roof insulation RSI (m^{2}·°C/W)	Nominal wall insulation RSI (m^{2}·°C/W)	Average glazing USI (W/m^{2}·°C)
Elementary school	3,079	3.6	2.1	5.2
Secondary school	11,562	3.3	2.7	5.1
Extended care	9,285	3.5	2.8	6.2
Hospital	40,372	3.3	2.8	5.4
Grocery store/restaurant	4,855	3.3	2.1	4.6
Stand-alone retail	13,521	2.4	1.7	5.3
Large mall	23,513	1.8	3.1	4.9
Low-rise office	3,625	2.9	2.6	3.8
High-rise office	11,648	2.9	2.1	5.1
Motel/hotel	26,753	3.4	3.1	5.1
High-rise multi-unit residential	13,293	3.6	2.8	3.7
Total/average	10,929	3.1	2.5	4.8

The average nominal roof insulation level was 3.0 m^{2}·°C/W. The highest RSI level for nominal roof insulation was for the elementary school and the high-rise multi-unit residential segments (3.6 m^{2}·

°C/W) while the lowest RSI level was for the large mall segment (1.8 m^{2-}°C/W). The average nominal wall insulation level was 2.5 m^{2-}°C/W 2.5. The highest RSI level for nominal roof insulation was for the large mall and motel/hotel segments (3.1 m^{2-}°C/W) while the lowest RSI level was for the stand-alone retail segment (1.7 m^{2-}°C/W). The average glazing heat loss level was 4.8 W/m^{2-}°C. The highest USI level was for the extended care segment (6.2 W/m^{2-}°C) while the lowest USI level was for the high-rise office segment (2.1 W/m^{2-}°C).

Space Cooling

Commercial space cooling requirements can be met through room air conditioning, central air conditioning, fans and heat pumps, while cooling needs can be reduced through appropriate insulation and shading. Table 3 provides characteristics and end use intensity for space cooling. The average saturation of space cooling is 70%.The highest saturation of space cooling is for the large mall segment (100%) while the lowest saturation of space cooling is for the high-rise multi-unit residential segment (4%). Recall that the coefficient of performance (COP) for a heat pump in the cooling mode is the ratio (in absolute value) of the heat removed from the cold reservoir to the input work. Key opportunities for improving space cooling efficiency include improved building envelopes, high efficiency motors and pumps, air-side economizers, ground water economizers, and improved and insulated ductwork.

Table 3. Space Cooling Characteristics and End Use Intensity

Building Segment	Saturation of Space Cooling (%)	Coefficient of Performance	Electricity EUI (kWh/m^2/y)
Elementary school	41	3.3	1.7
Secondary school	70	3.1	2.6
Extended care	67	3.3	11.2
Hospital	75	3.5	3.6
Grocery store/restaurant	92	2.8	16.8
Stand-alone retail	88	3.2	6.0
Large mall	100	3.5	19.0
Low-rise office	88	2.7	25.3
High-rise office	95	2.9	18.2
Motel/hotel	44	2.6	19.8
High-rise multi-unit residential	5	3.1	6.0
Total/average	70	2.6	12.9

Space Heating

Commercial space heating requirements can be met through a variety of technologies including steam boilers, hot water boilers, heat pumps, district energy systems and electric resistance heat. In the commercial sector in British Columbia, hot water boilers are dominant. Boiler efficiency is affected by boiler design, boiler age, fuel used, insulation levels on distribution systems and heat recovery equipment. Table 4 provides characteristics and end use intensity for space heating. Note that some buildings have both electric and natural gas space heat. The average saturation of electric space heating is 31%.The highest saturation of electric space heating is for the large mall segment (100%) while the lowest saturation of electric space heating is for the secondary school, extended care, hospital, and grocery store/restaurant segments (0%). The average saturation of natural gas space heating is 90%.The highest saturation of natural gas space heating is for the large mall segment (100%) while the lowest saturation of natural gas space heating is for the high-rise multi-unit residential segment (4%). Key opportunities for improving space heating energy efficiency include improved building envelopes, condensing heat recovery systems, non-condensing heat recovery systems, higher insulation on air distribution systems and regenerative burners which optimize the mix of fuel and air.

Table 4. Space Heating Characteristics and End Use Intensity

Building Segment	Saturation of electric heat (%)	Saturation of natural gas heat (%)	Electricity EUI (kWh/m^2/y)	Natural gas EUI (kWh/m^2/y)
Elementary school	12	94	8.8	140.5
Secondary school	0	100	-	108.4
Extended care	0	100	-	182.9
Hospital	0	100	-	334.0
Grocery store/restaurant	0	100	-	120.0
Stand-alone retail	13	88	10.0	59.4
Large mall	50	75	9.8	122.7
Low-rise office	83	83	47.6	93.5
High-rise office	30	100	13.5	93.5
Motel/hotel	13	100	81.0	112.0
High-rise multi-unit residential	68	100	26.9	97.7
Total/average	31	90	12.1	133.1

Interior Lighting

Interior lighting needs can be met with a variety of lamp, ballast, luminaire and control technologies, Table 5 provides characteristics and end use intensity for interior lighting. All the building modeled had interior lighting, so the saturation of interior lighting is 100%. Key opportunities for increasing interior lighting efficiency include reducing lighting intensity through de-lamping, increased use of day lighting, replacement of T12 fluorescent tubes with T8 and T5 fluorescent tubes, replacement of fluorescent ballasts with electronic ballasts, replacement of incandescent lamps with CFL and LED lamps, and improved lighting controls.

Table 5. Interior Lighting Characteristics and End Use Intensity

Building Segment	Saturation of interior lighting (%)	Power density (W/m^2)	Electricity EUI (kWh/m^2/y)
Elementary school	100	8.4	48.7
Secondary school	100	10.8	29.3
Extended care	100	9.2	51.1
Hospital	100	13.7	75.1
Grocery store/restaurant	100	21.1	240.0
Stand-alone retail	100	17.3	131.0
Large mall	100	26.9	92.6
Low-rise office	100	10.5	59.8
High-rise office	100	13.8	74.1
Motel/hotel	100	13.1	53.7
High-rise multi-unit residential	100	5.9	23.2
Total/average	100	13.8	79.9

Exterior Lighting

Exterior lighting needs can be met with a variety of lamp, ballast, luminaire and control technologies, Table 6 provides characteristics and end use intensity for exterior lighting. All the building modeled had exterior lighting, so the saturation of exterior lighting is 100%. Key opportunities for increasing exterior lighting efficiency include reducing lighting intensity, increased use of day lighting, replacement of T12 fluorescent tubes with T8 and T5 fluorescent tubes, replacement of fluorescent ballasts with electronic ballasts, and replacement of incandescent lamps with CFL and LED lamps.

Table 6. Exterior Lighting Characteristics and End Use Intensity

Building Segment	Saturation of exterior lighting (%)	Power density (W/m^2)	Electricity EUI (kWh/m^2/y)
Elementary school	100	2.6	15.4
Secondary school	100	1.2	3.3
Extended care	100	0.8	4.5
Hospital	100	1.4	7.6
Grocery store/restaurant	100	2.9	33.6
Stand-alone retail	100	1.7	13.4
Large mall	100	5.3	4.3
Low-rise office	100	2.5	13.9
High-rise office	100	3.2	17.3
Motel/hotel	100	2.9	12.0
High-rise multi-unit residential	100	5.1	20.0
Total/average	100	2.2	13.2

Equipment

Equipment in commercial buildings includes distribution transformers, data centre servers, other IT equipment, computers, monitors, printers and fax machines, video displays, security systems and medical imaging equipment. Table 7 provides characteristics and end use intensity for equipment. All the building modeled had equipment, so the saturation of equipment is 100%.

Table 7. Equipment Characteristics and End Use Intensity

Building Segment	Saturation of equipment (%)	Electricity EUI (kWh/m^2/y)
Elementary school	100	9.7
Secondary school	100	9.6
Extended care	100	16.4
Hospital	100	33.0
Grocery store/restaurant	100	32.0
Stand-alone retail	100	18.3
Large mall	100	7.6
Low-rise office	100	42.2
High-rise office	100	46.5
Motel/hotel	100	11.8
High-rise multi-unit residential	100	14.9
Total/average	100	22.1

HVAC Auxiliaries

HVAC auxiliaries in commercial buildings include fans and pumps used to distribute heated and chilled water and air. Table 8 provides characteristics and end use intensity for HVAC auxiliaries. All the building modeled had HVAC auxiliaries, so the saturation of HVAC auxiliaries is 100%. Key opportunities for increasing energy efficiency in HVAC auxiliaries include high efficiency motors, energy efficient fans and pumps, and adjustable speed drives.

Table 8. HVAC Auxiliaries Characteristics and End Use Intensity

Building Segment	Saturation of HVAC auxiliaries (%)	Electricity EUI ($kWh/m^2/y$)
Elementary school	100	24.0
Secondary school	100	22.7
Extended care	100	44.4
Hospital	100	48.6
Grocery store/restaurant	100	67.7
Stand-alone retail	100	40.3
Large mall	100	22.2
Low-rise office	100	32.7
High-rise office	100	49.0
Motel/hotel	100	47.6
High-rise multi-unit residential	100	4.5
Total/average	100	36.7

Refrigeration

Refrigeration in commercial buildings include refrigeration and freezing equipment. Table 9 provides characteristics and end use intensity for refrigeration. Key opportunities for increasing energy efficiency in refrigeration include increased insulation levels, energy efficient motors and compressors, adjustable speed drives and high efficiency motors.

Table 9. Refrigeration Characteristics and End Use Intensity

Building Segment	Saturation of refrigeration (%)	Electricity EUI ($kWh/m^2/y$)
Elementary school	0	-
Secondary school	0	-
Extended care	100	9.1
Hospital	100	6.1
Grocery store/restaurant	100	185.0
Stand-alone retail	0	-
Large mall	100	1.2
Low-rise office	0	-
High-rise office	0	-
Motel/hotel	100	5.5
High-rise multi-unit residential	100	5.0
Total/average	48	18.8

Vertical Transportation

Vertical transportation needs can be met through elevators and escalators. Table 10 provides characteristics and end use intensity for vertical transportation. All buildings except elementary schools and large malls had vertical transportation equipment. Key opportunities for increasing energy efficiency increased high efficiency motors, adjustable speed drives and advanced controls.

Table 10. Vertical Transportation Characteristics and End Use Intensity

Building Segment	Saturation of vertical transportation (%)	Electricity EUI ($kWh/m^2/y$)
Elementary school	0	-
Secondary school	100	0.8
Extended care	100	4.7
Hospital	100	7.1
Grocery store/restaurant	100	2.2
Stand-alone retail	100	4.8
Large mall	0	-
Low-rise office	100	4.4
High-rise office	100	4.2
Motel/hotel	100	4.1
High-rise multi-unit residential	100	2.0
Total/average	83	2.8

Domestic Hot Water

Domestic hot water needs can be met though steam boilers, water boilers, hot water tanks and heat pumps. Table 11 provides characteristics and end use intensity for domestic hot water. The average saturation of electric water heating is 14%. Key opportunities for improving water heating energy efficiency include improved insulation, condensing heat recovery systems, non-condensing heat recovery systems, higher insulation on air distribution systems and regenerative burners which optimize the mix of fuel and air.

Table 11. Domestic Hot Water Characteristics and End Use Intensity

Building Segment	Saturation of electric heat (%)	Saturation of natural gas heat (%)	Electricity EUI ($kWh/m^2/y$)	Natural gas EUI ($kWh/m^2/y$)
Elementary school	29	71	0.8	8.1
Secondary school	0	100	-	12.1
Extended care	0	60	-	14.2
Hospital	0	100	-	56.1
Grocery store/restaurant	8	92	0.8	144.2
Stand-alone retail	38	50	0.5	3.0
Large mall	25	75	1.5	1.5
Low-rise office	67	33	4.0	14.5
High-rise office	9	35	0.7	4.0
Motel/hotel	0	75	-	28.1
High-rise multi-unit residential	5	95	1.8	39.5
Total/average	14	71	0.9	29.6

Cooking

Cooking needs can be met though ovens, cook tops and micro wave ovens. Table 12 provides characteristics and end use intensity for cooking. The saturation of electric cooking was 27% while the saturation of natural gas cooking was 26%. Key opportunities for increasing energy efficiency in cooking include higher insulation levels and microwave ovens.

Table 12. Cooking Characteristics and End Use Intensity

Building Segment	Saturation of electric cooking (%)	Saturation of natural gas cooking (%)	Electricity EUI ($kWh/m^2/y$)	Natural gas EUI ($kWh/m^2/y$)
Elementary school	6	0	1.0	-
Secondary school	60	20	1.2	1.0
Extended care	0	60	-	12.0
Hospital	0	100	-	22.3
Grocery store/restaurant	15	85	50.2	304.9
Stand-alone retail	13	39	0.2	4.6
Large mall	100	0	1.5	-
Low-rise office	17	0	1.4	-
High-rise office	33	0	0.5	-
Motel/hotel	0	75	-	29.4
High-rise multi-unit residential	5	0	0.7	-
Total/average	17	26	6.3	38.4

Unit Energy Consumption

Table 13 provides the electricity UEC, the natural gas UEC, the total UEC and the ratio of total energy used for a building compliant with the ASHRAE 90.1-2004 benchmark. Recall that the UEC for each end use is the product of the EUI and the saturation rate for that end use. Note that for convenience both electricity and natural gas consumption are expressed in $kWh/m^2/y$.

Average electricity UEC is 187.6 $kWh/m^2/y$, with the highest electricity UEC in the grocery store/restaurant segment (583.8 $kWh/m^2/y$) and the lowest electricity UEC in the secondary school segment (68.2 $kWh/m^2/y$). Average natural gas UEC is 196.3 $kWh/m^2/y$, with the highest natural gas UEC in the grocery store/restaurant segment (569.0 $kWh/m^2/y$), and the lowest natural gas UEC in the stand-alone retail segment (75.6 $kWh/m^2/y$). Average total UEC is 383.9 $kWh/m^2/y$, with the highest total UEC in the grocery store/restaurant segment (1152.8 $kWh/m^2/y$) and the lowest total UEC in the secondary school segment (189.7 $kWh/m^2/y$).

Average ratio of energy used to the ASHRAE 90.1-2004 benchmark is 1.3, with the highest ratio for the large mall segment (1.7), and the lowest ratios in the secondary school, extended care, and grocery store/restaurant segments (1.0).

Table 13. Unit Energy Consumption

Building Segment	Electricity UEC (kWh/m^2/y)	Natural Gas UEC (kWh/m^2/y)	Total UEC (kWh/m^2/y)	Ratio of Energy Used to ASHRAE 90.1
Elementary school	99.8	156.3	256.1	1.2
Secondary school	68.2	121.5	189.7	1.0
Extended care	136.0	253.1	389.1	1.0
Hospital	181.1	392.3	573.4	1.6
Grocery store/restaurant	583.8	569.0	1152.8	1.0
Stand-alone retail	213.3	75.6	288.9	1.2
Large mall	153.7	159.0	312.7	1.7
Low-rise office	218.0	79.1	297.1	1.2
High-rise office	212.7	93.5	306.2	1.6
Motel/hotel	153.9	130.3	284.2	1.4
High-rise multi-unit residential	88.3	118.9	207.2	1.3
Total/average	187.6	196.3	383.9	1.3

Conclusion

Building Characterization. The average floor area for the 124 buildings in the sample was 10,929 m^2. The largest average floor area was for the hospital segment while the smallest average floor area was for the elementary school segment. The average nominal roof insulation level was 3.0 m^{2}-°C/W. The highest RSI level for nominal roof insulation was for the elementary school and the high-rise multi-unit residential segments (3.6 m^{2}-°C/W) while the lowest RSI level was for the large mall segment (1.8 m^{2}-°C/W). The average nominal wall insulation level was 2.5 m^{2}-°C/W. The highest RSI level for nominal roof insulation was for the large mall and motel/hotel segments (3.1 m^{2}-°C/W) while the lowest RSI level was for the stand-alone retail segment (1.7 m^{2}-°C/W). The average glazing heat loss level was 4.8 W/m^{2}-°C. The highest USI level was for the extended care segment (6.2 W/m^{2}-°C) while the lowest USI level was for the high-rise office segment (2.1 W/m^{2}-°C).

Total Energy Consumption. We measured unit energy consumption (UEC) based on weather adjusted billing data. Average electricity UEC was 187.6 kWh/m^2/y, with the highest electricity UEC in the grocery store/restaurant segment (583.8 kWh/m^2/y) and the lowest electricity UEC in the secondary school segment (68.2 kWh/m^2/y). Average natural gas UEC was 196.3 kWh/m^2/y, with the highest natural gas UEC in the grocery store/restaurant segment (569.0 kWh/m^2/y), and the lowest natural gas UEC in the stand-alone retail segment (75.6 kWh/m^2/y). Average total UEC was 383.9 kWh/m^2/y, with the highest total UEC in the grocery store/restaurant segment (1152.8 kWh/m^2/y) and the lowest total UEC in the secondary school segment (189.7 kWh/m^2/y).

End Use Energy Consumption. We estimated end use intensities (EUIs) based on modelled information. For electricity, the EUIs were 12.1 kWh/m^2/y for space heating, 79.9 kWh/m^2/y for interior lighting, 13.2 kWh/m^2/y for exterior lighting, 22.1 kWh/m^2/y for equipment, 36.7 kWh/m^2/y for HVAC auxiliaries, 18.8 kWh/m^2/y for refrigeration, 2.8 kWh/m^2/y for vertical transportation, 0.9 kWh/m^2/y for water heating, and 6.3 kWh/m^2/y for cooking. For natural gas, the EUIs were 133.1 kWh/m^2/y for space heating, 29.6 kWh/m^2/y for water heating, and 38.4 kWh/m^2/y for cooking,

Benchmark Comparison. Average ratio of energy used to the ASHRAE 90.1-2004 benchmark was 1.3, with the highest ratio for the large mall segment (1.7), and the lowest ratios in the secondary school, extended care, and grocery store/restaurant segments (1.0).

Energy Efficiency Opportunities. Energy efficiency opportunities included improved building envelopes, high efficiency motors and pumps, air-side economizers, ground water economizers, improved and insulated ductwork, condensing heat recovery systems, non-condensing heat recovery systems, higher insulation on air distribution systems, regenerative burners, increased use of day lighting, replacement of T12 fluorescent tubes with T8 and T5 fluorescent tubes, replacement of fluorescent ballasts with electronic ballasts, and replacement of incandescent lamps with CFL and LED lamps.

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Session

Building Energy Management

eu.bac System

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Abstract

State-of-the-art building automation systems are energy-efficient and sustainable. Recently the European Building Automation and Controls Association (eu.bac) has revealed the potential for increasing energy efficiency in buildings with a system certification independent of the manufacturer.

The Energy Performance of Buildings Directive (EPBD), which was adopted by the EU in 2002 and revised in 2010, is an important step towards the improvement of the energy efficiency of the large stock of existing buildings in Europe. As a result, more than forty EN standards have been developed with the aim of harmonizing the methods of calculating the energy consumption of buildings in Europe. EN 15232 [1] shows how building automation can be used to minimize energy consumption.

The new 'eu.bac System' methodology assesses building automation based on the EN 15232 standard [1]. Thanks to the weighting of the features across the supplied area and running time, the audit also serves as an important decision-making basis for improvement initiatives.

The 'eu.bac System' consists of the parts “Analysis of the installed building automation system” and “Key figures: Unified set of key performance indicators (KPI) for continuous monitoring of the operation of the building automation system”.

The auditing of a building automation system represents an ideal basis for optimizing the installation – so-called 'continuous commissioning' – and supports building automation manufacturers services with recognized standards. This leads to the sustainable operation and maintenance of building value throughout its life time.

The European Building Automation and Controls Association (eu.bac) was founded in 2003. It membership comprises both manufacturers and service providers. Its objectives are to promote building automation, ensure product quality and to actively support CEN/ISO standardization and European directives.

Introduction

The primary purpose of a building is the provision of space for working, living, presentations, pleasure, etc. Each building must satisfy the user requirements. The most favourable conditions possible for humans and furnishings must be created in the building.

The building automation ensures that, depending on the use requirements of the building, optimal climatic conditions prevail. It links all existing systems in a building and optimises the interaction in terms of the best ambient conditions with maximum energy efficiency. The prerequisite for energy efficiency at a desired level of comfort is an intelligent building automation system that provides the required energy in the right quantity at the right time and at the right place.

A large proportion of the heating, cooling, air conditioning and lighting provided in the building is wasted. This means they are activated and consuming energy even when this results in no benefit at all.

Effective measures for preventing waste are described in the European standard EN 15232 [1]. The principle or central theme in this standard is needs-based operation of the systems. Energy in the form of heat, cold, conditioned air and lighting should only be provided when there is demand on the user side (Fig. 1). Usage and thus, in large part, the users dictate when and how much energy must be consumed. Systems with consistent, automatic identification of needs with, for example, occupancy detectors and a room control which requests the energy requirement in a targeted manner in energy processing, achieve the highest energy efficiency class.

The basic principle is: Use energy only when it results in a benefit.
Eliminate waste!

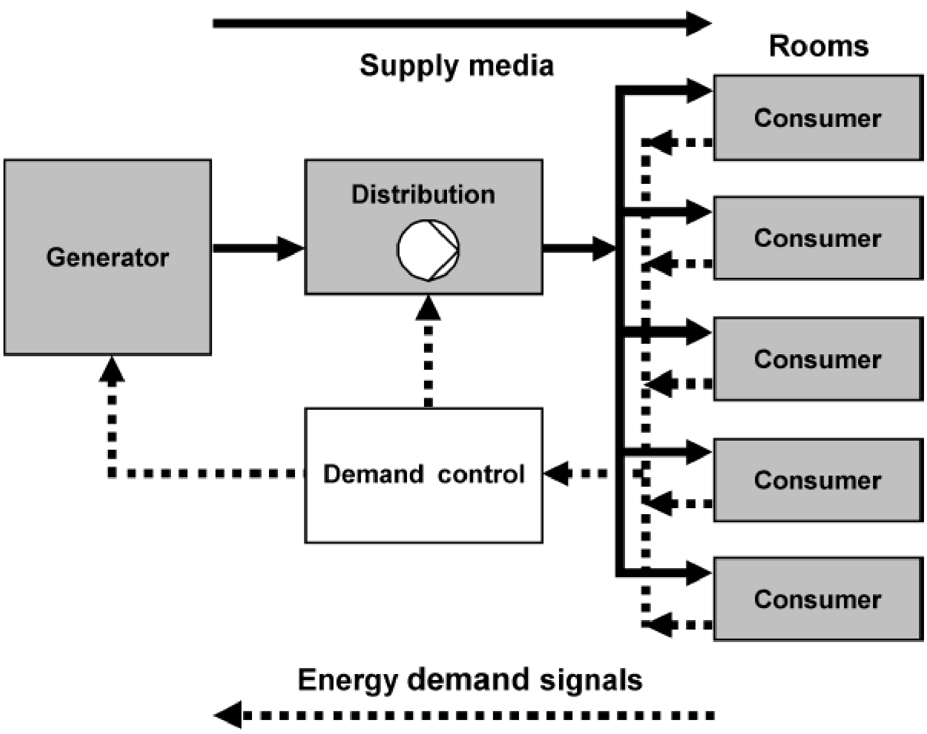


Fig. 1: Demand control according to EN15232

A demand-led control strategy can be used in any building, regardless of its age, façade, etc., and always leads to significant energy savings compared to constantly supplying the building.

Sustainable building automation

From what perspective is building automation sustainable? Let us assume a serviceable life of a building ranging from several decades to 100 years. It is very likely that the use of the building will change more than once during this time. Even if the purpose remains the same (the office building remains an office building), the requirements for operation continuously change based on use. These changes in use are driven by changing tenants, adaptation to economic changes, technological changes, generational changes and changing socio-cultural requirements. In addition, technical development cycles are getting shorter and regulatory requirements are increasing. This often results in increased operating and maintenance costs. The reason for rising costs is usually that the supply to the building is not adapted to changing requirements.

A building automation system can be described as sustainable if it can adapt to changes in use over the long term and bring about ecological, social and economic benefits.

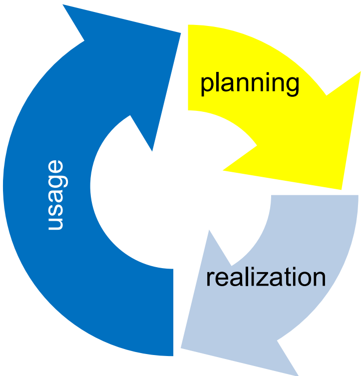
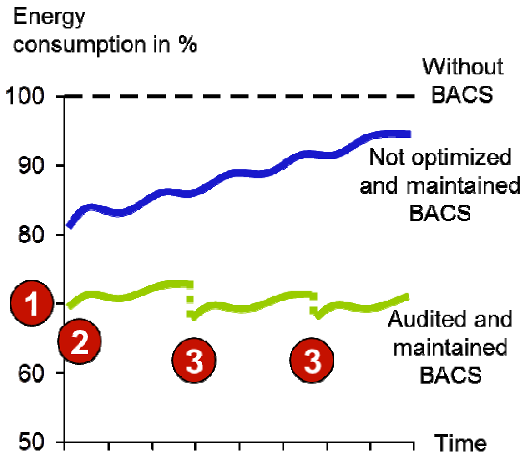


Fig. 2: Life cycle of a building

The energy-saving potential and life-cycle aspects that can be achieved through building automation are not considered comprehensively enough in current building certifications such as LEED, DGNB, etc. Fig. 2 illustrates the 3 major sections of a building life cycle: Planning, realization and usage.

With the new audit methodology eu.bac System, this gap is closed. The procedure is based on the existing standard EN 15232 and was empirically tested by Dresden University of Technology. These system audits help to save energy and reduce operating costs throughout the entire life cycle and ensure efficient and sustained operation. The installed equipment is checked periodically. In this way, deviations from the state of the building automation during commissioning or deviations from the current usage can be identified, allowing corrections to be made.

Fig. 3 illustrates the effects of regularly audited and optimised operation and a system that is thus adapted to changing use requirements.



1. Standardised, energy-efficient functionality
   - Optimal specification of a BA system with the best cost-benefit ratio
2. Guaranteed functionality
   - Using the first audit to check the ordered and the installed functionality
   - Standard handover report
3. Guarantee of sustained operation
   - Guaranteed availability and functionality of the system
   - Compliance with comfort specifications
   - All parameters undergo thorough checks
   - Compliance with the specified energy-efficiency class

Fig. 3: Illustration of the effect of a building automation system audited and optimised during operation

eu.bac and its tasks

eu.bac is the European association [2] of manufacturers of home and building automation systems. In terms of its economic potential, eu.bac is the largest European platform dedicated to intelligent buildings and its effect on energy efficiency of buildings. eu.bac makes its expertise available not only to member companies but also the entire economic and political community.

Auditing according to eu.bac System

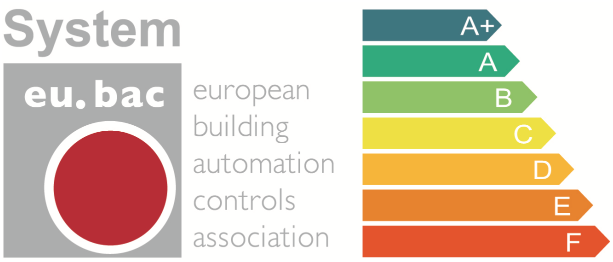


Fig. 4: Assessment of building automation

eu.bac System [3] is a new methodology for the audit and certification of a building automation system on the basis of EN 15232. Fig. 4 shows the logo of eu.bac System.

The method can be applied over the entire life cycle of a building.

Beginning in the planning phase, planners are given a powerful tool for simulating the use of the functions described in EN 15232. Thanks to the weighting of the individual functions over the period of use and the area supplied, the right priorities can be set for planning and implementation.

We always follow the principle – “use energy where it results in a benefit”.

After completion of commissioning, the certificate produced in accordance with eu.bac System documents the installed functional status to the future building operator. At this point in time the certificate forms a basis for future adjustments of the functions installed to the actual operation i.e. to the real use of the building.

This serves as a contribution to overcoming the still prevalent investor-user dilemma.

During the use of the building, differences from the state was in when it was commissioned are detected through periodic re-auditing. In this way the building automation system parameters can be adjusted to its effective use. This allows the building automation system to be adapted to the actual usage. The re-audit is thus a component of continuous commissioning, making it part of a traceable process which in turn is based on relevant standards. Fig. 5 illustrates the application of eu.bac System methodology through the phases of the building life cycle.

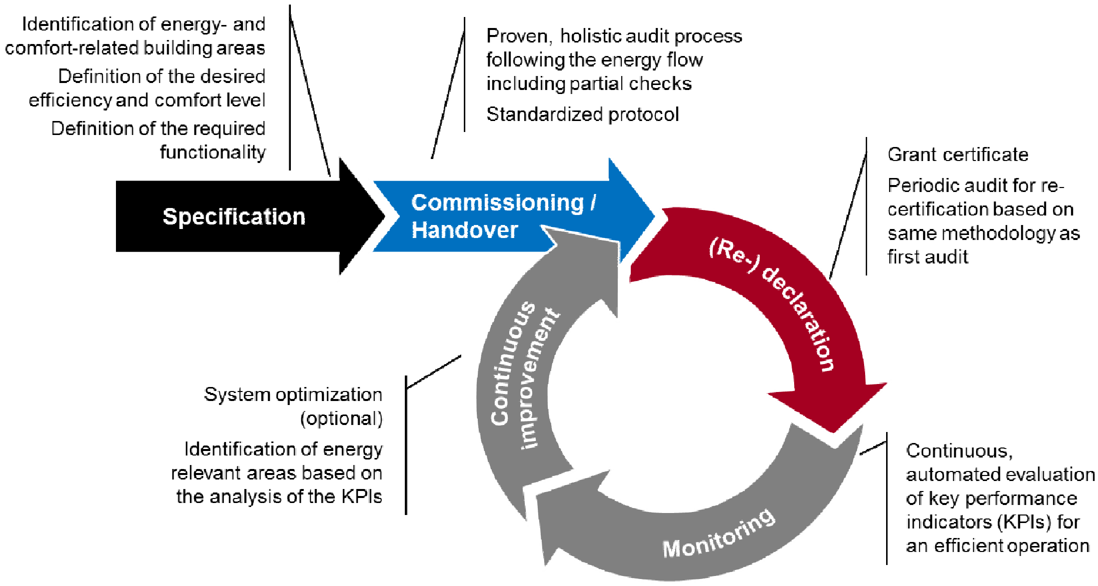


Fig. 5: Application of eu.bac System in the life cycle of the building

With auditing according to eu.bac System and implementation of the findings obtained through the audit, sustainable operation is achieved. This leads to long-term optimisation of energy and operating costs, thus making a decisive contribution toward maintaining the value of the property.

In the renewal and renovation phase, the right decisions can then be made in turn in favour of energy-optimised operation thanks to the use of functions weighted through use.

The functions of EN15232 are weighted in 3 levels:

1. Usage type of the building
2. Period of use
3. Supplied areas

Usage types: For the usage types “office, data centre, school, hospital, hotel, department store, restaurant, residential building”, weighting factors for the different equipment systems were developed in collaboration with the Technical University of Dresden and included in the inspection tool.

Assessment is based on a points system and is normalised to a 0–100 scale. For presentation that is appealing to the public, the result is further illustrated with the help of a label with the grades of A+ to F. Based on the calculation methods described in EN 15232, conclusions can be drawn regarding the potential for energy savings. An improvement of 10 points corresponds to energy savings of approx. 5%. These values, of course, depend very much on the individual object to be evaluated and should be considered as recommended values. Fig. 6 shows an example of the final result of an eu.bac System certification.

POINTS AND CLASS SUMMARY					POINTS
Section	Description	Importance	Actual Imp.	Norm. Score	Result
1	Heating control	10	10.00	97.92	17
2	Domestic hot water supply control	2	2.00	89.25	3
3	Cooling control	10	10.00	94.97	17
4	Ventilation and air conditioning control	10	10.00	87.68	15
5	Lighting control	5	5.00	100.00	9
6	Blind control	5%	2.87	100.00	5
7	Technical building management	10	10.00	100.00	17
8	eu.bac Key Performance Indicators	5%	2.87	46.51	2
9	eu.bac Extended Functionality	5%	2.87	55.56	3
10	eu.bac Certified Products	3%	1.72	100.00	3
NORMALIZED TOTAL (0-100)			57.32		91
			eu.bac System (F..A+):		A+

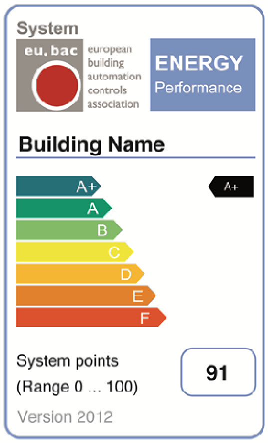


Fig. 6: Result and representation

The audit according to the eu.bac System is carried out by eu.bac-accredited auditors. Each auditor must complete official training of eu.bac with a final test. Upon successful completion and successful audit of a building, the auditor is listed officially by eu.bac as an accredited auditor.

Key performance indicators (KPI)

The eu.bac System key performance indicators are a set of key figures derived from the operating data in a building automation system with information on:

- Energy efficiency of a building automation system / components
- Diagnosis through calibration of the plant
- Manual operation over long periods of time
- Adherence to comfort conditions (temperature, humidity, indoor air quality)

KPIs are calculated at the automation level, compacted to daily values and presented each day using a “traffic light” system.

The key performance indicators enable ongoing assessment of the performance of the building automation system and its components. With the help of these indicators, operators can detect and optimise settings that differ from actual use. For energy consultants, they also constitute a reliable data source and are the basis for energy optimisation. The basic principle here is: The greater the level of instrumentation and the finer the resolution, the more accurate the information.

Colour	Interpretation in the observed period	Measures to be taken before a re-audit
Green	90% of the daily key performance indicators are in the “green” range	No action necessary
Yellow	Between 10% and 19% of the daily key performance indicators are outside the “green” range	A building automation system with such a value passes the eu.bac System certification once. In the next recertification, corrections need to be made in the system.
Red	More than 20% of the daily KPI values are outside of the “green” range	Measures must be carried out before the next declaration. No certificate can be issued if there are “red” KPIs.

Table 1: Evaluation of key performance indicators

Example of a KPI:

Monitoring room/zone heating regulation or heating requirements

Objective:	Warns against overheating in zones/rooms, errors in the heating control output
Approach:	Time is accumulated for one day (00:00 – 23:59): “consolidated heating setpoint +0.5 K” with actual value AND “heating control output > 0” during occupancy in relation to the actual period of use
Rating:	Red: Time > 20% Yellow: Time 10%..19% Green: Time < 10%

Results

As of July 2013, 12 auditors have been officially accredited by eu.bac. 11 more auditors have completed the training and will soon be auditing a building.

Many buildings have been audited and certified in Germany and Switzerland. The results vary from 33 points (label F) to 86 points (label A+). The lowest results come mainly from existing buildings. The methodology allows the potential for subsequent installations and optimisations to be demonstrated using concrete examples. The high ratings (label A and A+) are found in buildings where special attention was paid to sustainability during construction. Most of these buildings are also certified according to LEED or DGNB and achieve the best results under those systems.

Conclusion, summary

State-of-the-art building automation systems are energy-efficient and sustainable. Recently eu.bac has revealed the potential for increasing energy efficiency in buildings by building automation with a system certification independent of the manufacturer. This is based on a scientifically-proven approach, the European standard EN 15232 and a methodically examined, standardised process. This provides the end customer with security and comparability.

eu.bac System provides planning security, transparency and efficiency in planning and construction. It also allows optimum specification and implementation of the control requirements thanks to identification of the energy- and comfort-related areas of the building. In the implementation and handover of the building automation system, the functionality of the installed technology is uniformly documented, and proof of correct function is provided. In existing buildings, the structured condition analysis and evaluation enables sustainable operation through recording of energy savings potential and continuous monitoring and adaptation.

Today the companies as followed are already participating in eu.bac System: Belimo, Dial, Honeywell, Johnson Controls, Kieback & Peter, SAUTER, Schneider Electric, Siemens, WSP.

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[2] eu.bac: http://www.eubac.org: European Building Automation Controls Association

[3] eu.bac System: http://system.eubac.org

Applying model-based control strategies to an office building

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Abstract

Model-based control is a well-established technique to solve complex control tasks and is currently employed in industrial applications. Using a model of the controlled process to predict its behavior and thus optimize operation was shown to improve various industrial processes. Building automation has not yet exploited the potential of this technology, although it has the capability to address the upcoming challenges for energy efficient buildings. This paper demonstrates how model-based control can be used in a building automation system in order to improve building energy management. This paper explains the overall development process, i.e. the development of the model to be controlled, the comparison to the conventional control strategies. Furthermore it will be shown how the innovative control strategy is implemented with a case study where a weather predictive control strategy is realized for the ENERGYbase office building, with the aim of reducing the heating demand of the building. Using the predicted outdoor air temperature and solar radiation and a thermal model of the building, the building automation is improved. Thereby, heating demand is reduced significantly. The overall control system configuration is optimized in simulation runs, where system state set-points are recalculated for the purpose of heating demand reduction. This demonstrates the versatility of model-based control, as well as applicability in building automation.

Keywords: *Thermodynamic system models, Model-based control strategies, Optimization, Energy reduction, Office building*

Introduction

Functional buildings like office buildings are already mostly equipped with a building automation system responsible for the needs of the building users, e.g. maintaining indoor comfort and catering. The technical approaches for governing systems like Heating Ventilation and Air Conditioning (HVAC) or lighting are to describe the desired behavior programmatically by means of control strategies. Those can be divided in two levels of hierarchy, automation and control. In automation the conditions are defined in which a system (e. g. a heat pump) should operate and what set-points it should achieve. This is the state the control should achieve, ensuring that the set-point (or set-point trajectory) is followed. Automation is commonly solved by defining conditions at which the system enters a new state (much like state diagrams, augmented by more complex conditions that can depend on system values, states or temporal conditions). The controls are almost exclusively linear controllers, especially P- and PI-controllers.

Control strategies allow operating a building that maintains indoor comfort in all aspects. The complexity of state-of-the-art systems requires careful design of these strategies which is manageable, but not well supported by the available tools. There is commonly no test phase where the strategies are thoroughly validated, tested for completeness, deadlocks, unreachable states etc. A more recent requirement for building automation is also that instead of only maintaining indoor comfort, the operation of the building shall also be energy efficient. This constraint requires review of the control strategies not only for correct operation, but also for energy optimality - a task which is much harder to achieve than bare function testing. Even more, once an operation mode has been identified to be inefficient, the question on how to improve it has to be addressed. Again it can be solved by the expert, who designed the control strategies, but it requires manual optimization.

Model-based predictive control (MPC), an approach that is well known in industrial processes for the last decades, promises to address these issues. It has several advantages over traditional controls that also prove helpful in the area of building automation. In this paper, the focus is on the energy efficiency of an office building and optimizing energy use on management level using model-based controls. The first and most important step is to create a model of the process which is to be optimized. In this case the process is the building with its physical properties of walls, floors, ceilings, windows, etc. and the energy systems that ensure indoor comfort i.e. the HVAC systems (heating, ventilation and air conditioning). Using this model the controller has a significant benefit over a linear controller. It can feed the model with starting conditions and calculate the behavior, therefore predicting how the plant will react in the future. In MPC this is done up to a certain time horizon, called the prediction horizon.

Next, the disturbances that act on the building have to be fed into the controller. The controller can regard not only current disturbances, but can also take predicted disturbances into consideration, e.g. the weather forecast for the next day.

Aside of the building model and the disturbance predictions it is also necessary to define the optimization target, the objective function. Using the model the controller simulates the behavior of the building and evaluates the outcome based on the objective function. By modifying the control parameters it can do an optimization until the objective function shows improvement up to a (local) optimum. This way the controller can optimize the building operation for the near future e.g. the next few hours. The operator of the building has the benefit of a system that reacts flexibly on changes (e.g. changing weather conditions) and not having to rely on control strategies that are defined when constructing the building without the possibility to change them easily when optimization is required.

State of the Art

In order to successfully optimize a building with regards to its energy demand, an increased resolution in detail may be feasible. However, commercial models commonly exhibit a high degree of complexity and hence are usually not suitable for optimization purposes. Such complex models were used for instance in the project ProKlim[1] [1].

To fully explore the advantages of optimization, simplified representation of complex models should be considered. One possibility has been defined within the scope of the German standard VDI 6020, known as “Beuken-Model” [2]. Using this approach a thermal zone of a building is represented by a network of capacitances and resistances. Recent studies found out that the simplification of building models result in a reduction of modeling costs [3]. Simplification allows to cut-off on modeling effort and generates the development of dependent technologies (for example in [4] and [5]).

A different approach regarding optimization of buildings is to focus on the energy components directly. This results in detailed modeling of the system to be controlled, in this case the HVAC components and their control strategies. There have been several studies which point out the potentials of model-based control compared to conventional control strategies with regards to energy-efficient control operation improvements on the process-oriented level [6].

Several studies have successfully outlined the importance to include weather forecast into the building automation by which energy savings were achieved [7],[8],[9]. The principle behind this is using the weather information together with the knowledge of the control strategy, day-head energy demand estimations, can be calculated and finally optimized. A case study based on this general idea will be show in the following section.

Methodology

Building model development

This section describes one possible way to apply model-based control in conjunction with optimization to an office building. The building, planned and constructed to achieve passive house standard, is called ENERGYbase and is located in the 21th district of Vienna. As in many passive house projects, an approach was to achieve high solar gains to help with the heating of the building, thus increasing the influence of direct solar radiation on the indoor temperature. The system to be controlled is the heating system realized with two heat pumps as energy source and concrete core activation (CCA)

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[1] funded by the Austrian Research Promotion Agency (FFG) within the “Haus der Zukunft Plus” program, project number 822261

within the ceiling elements for distribution. Due to limitations the model-based controller should only interact on the energy management level, resulting in controlling only the heating set-points of the ceiling elements without influencing the heat pumps directly e.g. changing the mass flow rates. Technically spoken, the control variables are the heating set-points of parts of the office building where the new controller will be applied. The basis for controller is a simplified but detailed enough model of the plant to be controlled where the main goal is to represent the system dynamics as close as to reality. This results in a simplified building and HVAC model of the heating system.

The basis of the simplified building model was a very detailed previously developed model of the ENERGYbase, but far too complex using it for model-based control. This model (reference model) was developed within the simulation environment TRNSYS and validated against monitoring data. Therefore a simplified model was developed based on the VDI 6020. This approach is a good compromise between complexity and model quality. The modeling approach includes building partitioning into thermal zones, where each zone is represented as a thermal RC-network (see figure 1).

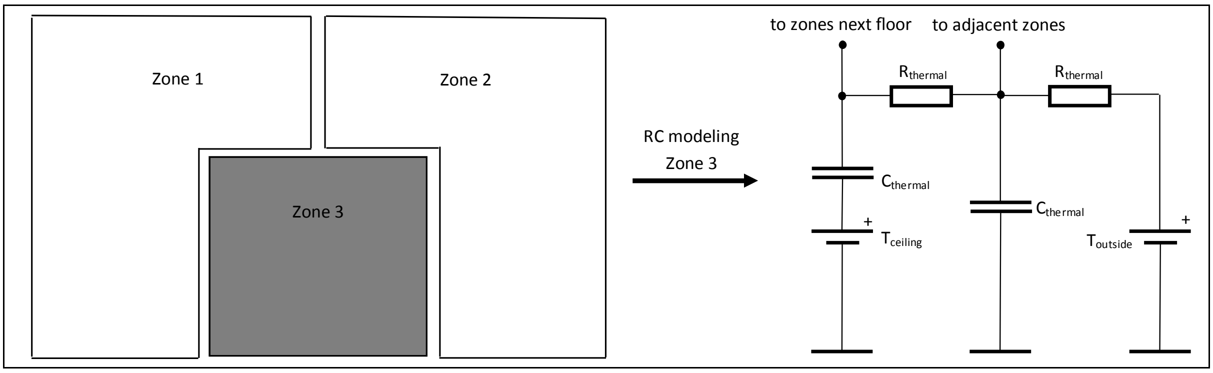

Figure 1: Simplified building model

Within the scope of the project a thermal building model of the 3rd floor (~1800m² floor area) of the ENERGYbase was developed within the simulation environment Dymola. In order to achieve the same dynamic behavior concerning the room temperatures compared to the reference model, the calibration process using a parameter variation of the RC components were made.

Building model validation

Finally the developed model was validated. Therefore recorded heat energy was applied to the building model as an input according to monitoring data from October 2009, where the building was not influenced by internal gains e.g. people, lighting, electric equipment, etc. Figure 2 shows the results of the validation for one week.

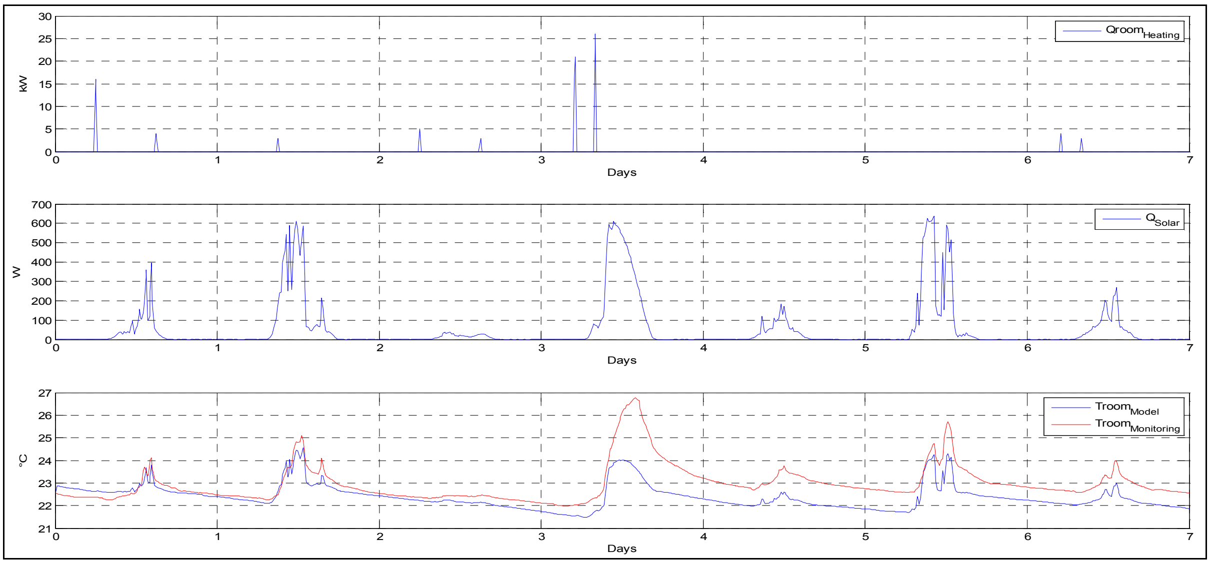

Figure 2: Validation- comparison between monitoring data and building model

The first subplots shows how much heat was applied to one reference zone, the second and the third subplot shows the surrounding conditions and the forth subplot shows the comparison between the results of the model (blue) and the monitoring data of the room temperature (red). The overall dynamic, in this case how the room temperature reacts due to the heating system or the solar gain is a reasonable fit. In the end a small deviation between monitoring data and model output arises which is an effect of wrong boundary conditions of the adjacent floors e.g. constant room temperatures in the 2nd and 4th floor, internal gains, etc. This cumulates over time, but is well beyond the prediction horizon to be employed in the control.

Optimization problem specification

In order to get the optimal solution concerning energy savings, an optimization problem resulting in a cost function was specified (see figure 3). The main goal was to minimize the electrical energy consumption of the two heat pumps representing the heating system, without influencing the comfort temperatures in the thermal zones. Therefore a penalty function f(x) was specified, which adds a penalty on the cost function whenever the room temperature is not in the specified range between 22.5° und 23.5° Celsius. The constraints – which interacts like soft constraints, can be therefore exceeded – were chosen very tight, to ensure that the overall room temperatures will be in the comfort band between 22° and 26° Celsius.

$$\int HP_1 dt + \int HP_2 dt + f(x) \rightarrow MIN$$

$$f(x) = \begin{cases} x^2, & x < 22,5 \\ 0, & 22,5 \leq x \leq 23,5 \\ x^2, & x > 23,5 \end{cases}$$

Figure 3: Optimization problem

The optimization problem will be solved with the optimization environment GenOpt. The reason for using it is it can be easily implemented within Dymola without huge programming effort because the communication between both tools is managed by simple text files. To achieve a good compromise between accuracy and calculation time concerning the optimization, a generalized pattern search algorithm was used. This is a hybrid GPS algorithm using particle swarm optimization [10]. Influencing the electrical energy consumption GenOpt will vary the heating set-points around a specified band, in order to reduce the electrical energy consumption of the heat pumps. The model will calculate the necessary heating set-points – the 3rd floor was divided into four individually controlled areas, resulting in four different set-points (NW, NE, SE, SW) – according to the current control strategy, whereas GenOpt calculates an offset which will be added to the original set-points. This influences the heating system in a way that energy savings are possible. Combining the building model, the optimization algorithm and the weather prediction, the new model-based controller was finally developed.

Implementation into the building management system

To apply the model-based controller to the building management system, the hardware in the loop (HIL) approach was used, where the main idea is to run the control strategies on an external computer and sent the results of the control variables to building management system.

After developing model-based controller, a framework serving as link to the building management system was developed (figure 4). The basis for communicating with the building a MySQL database was used. This database contains the necessary information which is needed for the model-based controller. The controller is performing its tasks on a standard office computer using MATLAB as master program. All communication is done by using MySQL, FTP or BACnet.

The goal of the model-based controller is using the behavior of the building model together with the weather forecast in order to optimize the heating set-points of the real building resulting in a reduction of the electric energy consumption of the heat pumps. Therefore following algorithm will be performed:

- Using BACnet, the database ensures that at any time of a query the current building data e.g. room temperatures, CCA temperatures, supply temperature of the heating system etc. will be provided.

- The master program is taking the current building data by using the MySQL from the database and feeding these parameters into the building model as initial states. Because of the architecture of the framework, a first simulation of the building for the next 24 hours is needed which is the basis for the optimization problem.
- Based on this initial model in combination with the weather forecast – made available by UBIMET GmbH – for the next 24 hours the optimizer will calculate the optimal heating set-points for the next 24 hours.
- Finally the master program re-simulates the building model with the optimization results and writes the optimized set-points back into the database again using MySQL.
- The database forwards the set-points to the corresponding BACnet object and the building management system ensures that the new set-points will be reached.

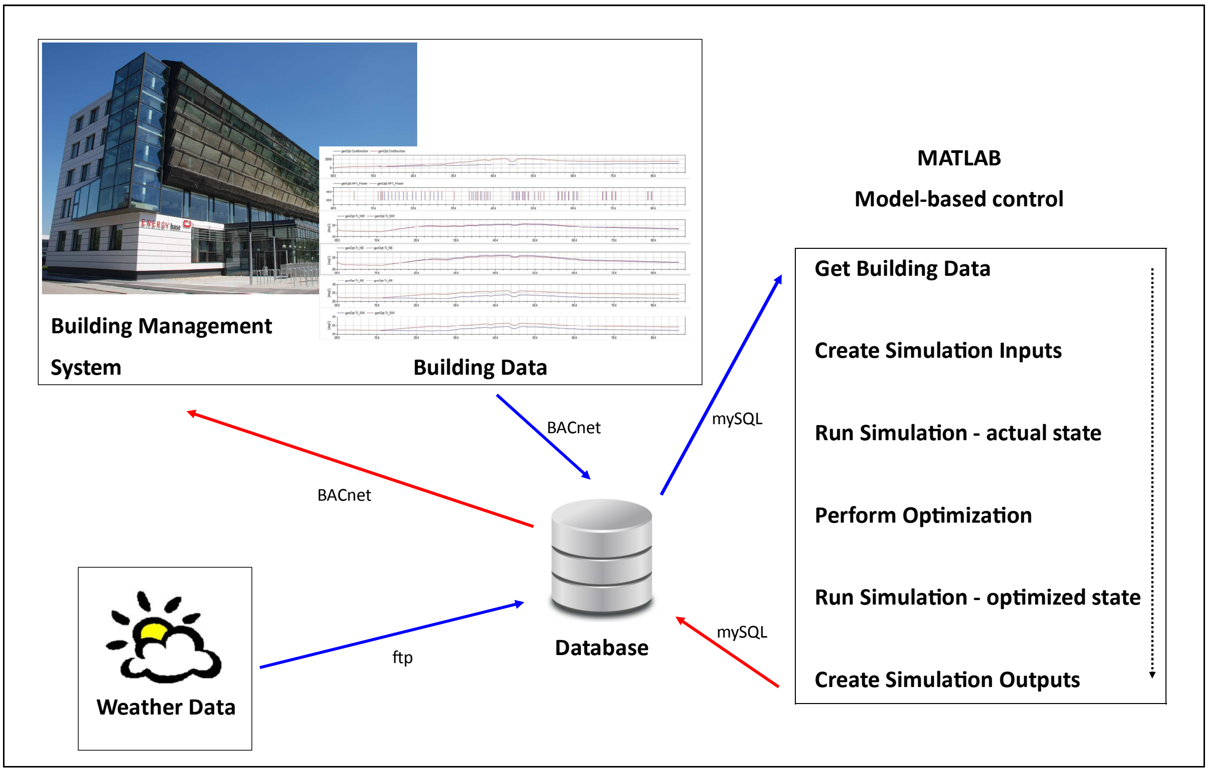

Figure 4: Framework for communication between building and controller

This HIL approach makes sure that only the building management system will be manipulated without influencing any subordinate controllers. Finally the developed framework serves as proof of concept if it is possible to generate savings in the heating system. The real implementation into the building has some limitations due to technical reasons or requirements from the facility manager: the predictive horizon is limited to 24 hours, every 3 hours a new optimization using the current building data and new weather forecast needs to be performed.

Offline solution

Due to risks with regards to a successful implementation of the controller into the building management system of the building, an "offline" simulation was realized in parallel, where the real building was simulated on the basis of the developed building model. The advantage of this approach is that possible savings can be easily identified by validation the results against the conventional control strategies.

In order to compare both strategies, a baseline simulation (conventional controller) was set up for a defined period e.g. a month. In the following the new controller optimized the control strategies for each day of the entire period separately. Therefore a second master program was developed for the sake of daily optimization runs. The critical part is to identify and provide the correct initial states e.g. room temperatures, status of the HVAC components, etc. For an optimization period of e.g. 2 days, the initial states for the second run (day 2) correspond to the states of (day 1). The establishment of the correct initialization variables proves to be the critical tasks in this simulation.

Results

The implementation of the model-based controller in the existing building (ENERGYbase) could not be realized within the project duration. Nevertheless it is foreseen that the developed methodology of implementing the controller in the building will be applied in a cognate running project. As mentioned before an offline simulation was developed in parallel in order to show possible savings of the new developed controller. The following paragraphs will summarize the outcome of the simulation for the period of February, with low ambient temperature and alternating solar radiation intensities:

The first step was to proof the effects of the model-based controller in general, using the correlation between the set-points and the mean solar radiation per day in south facade plane as shown in table1.

Table 1: Correlation between Q_{FLOW} (heat flows) / T_{SET} (set-points) and the mean solar radiation per day in south facade plane for each area

Mean solar radiation per day in south facade plane								
	without model-based control				with model-based control			
Area	NE	NW	SE	SW	NE	NW	SE	SW
Q_{FLOW}	-0.0269	0.0623	-0.1638	-0.1507	0.0836	0.0067	-0.3158	-0.1118
T_{SET}	-	-	-	-	-0.1482	-0.4046	-0.2528	0.1050

The results prove that the set-points (T_{SET}) in general lower the room temperature with increasing solar radiation (defined by a negative correlation coefficient). The effects can also be seen on the actual heat flow (Q_{FLOW}) into the four areas. The northern areas are naturally not influenced a lot by solar radiation which explains the weak correlation without and even with model-based control. The southern areas show a stronger correlation, especially area south-east (SE), where the morning sun instead of the heat pumps can be used to heat up this area. On the other hand the area south-west (SW) shows a positive correlation. This could be explained with lower temperatures in the morning on sunny days, which sometimes can lead to the necessity to heat up the area in the afternoon.

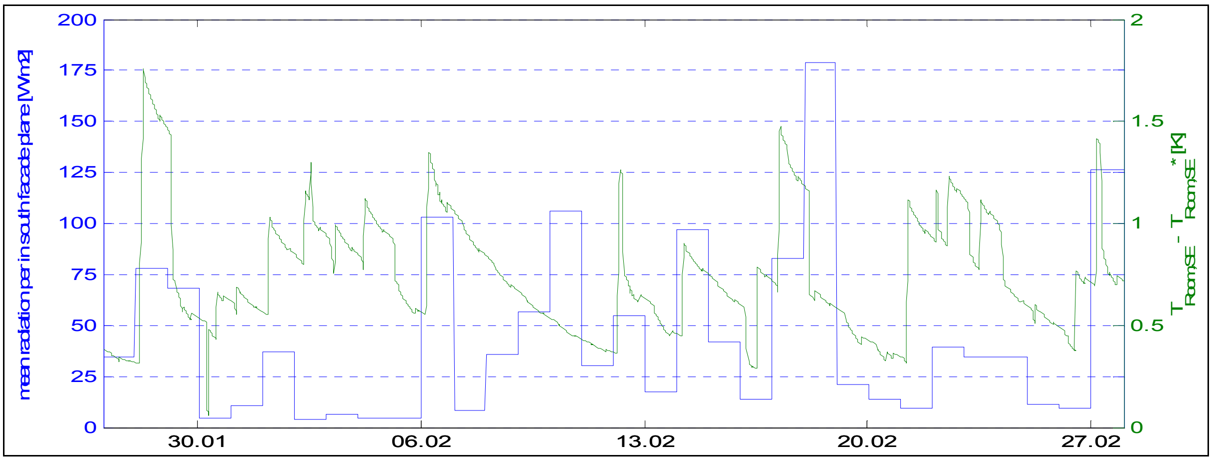

Figure 5: Time-series of mean solar radiation per day and the difference between $T_{ROOM,SE}$ and $T_{ROOM,SE}^*$

This correlation can be identified by focusing on area SE (figure 5) too, where the mean solar radiation per day and the difference between the room temperature without ($T_{ROOM,SE}$) and with ($T_{ROOM,SE}^*$) model-based control is plotted as time-series. Without model-based control the room tends to overheat on days with high solar irradiation, resulting in a big delta T between $T_{ROOM,SE}$ minus $T_{ROOM,SE}^*$.

Figure 6 shows the average room temperature of each controlled area to proof that with the model-based control algorithm the temperatures stay within the comfort band (22° to 26° Celsius). The northern temperatures (NW, NE) are basically similar to the original temperatures whereas the southern temperatures (SE, SW) differ more- especially between the 6th and 13th of February. Using the model-based control algorithm, it is possible to prevent overheating of the room temperature without activating the cooling system and reducing the heating demand of the heating system in parallel.

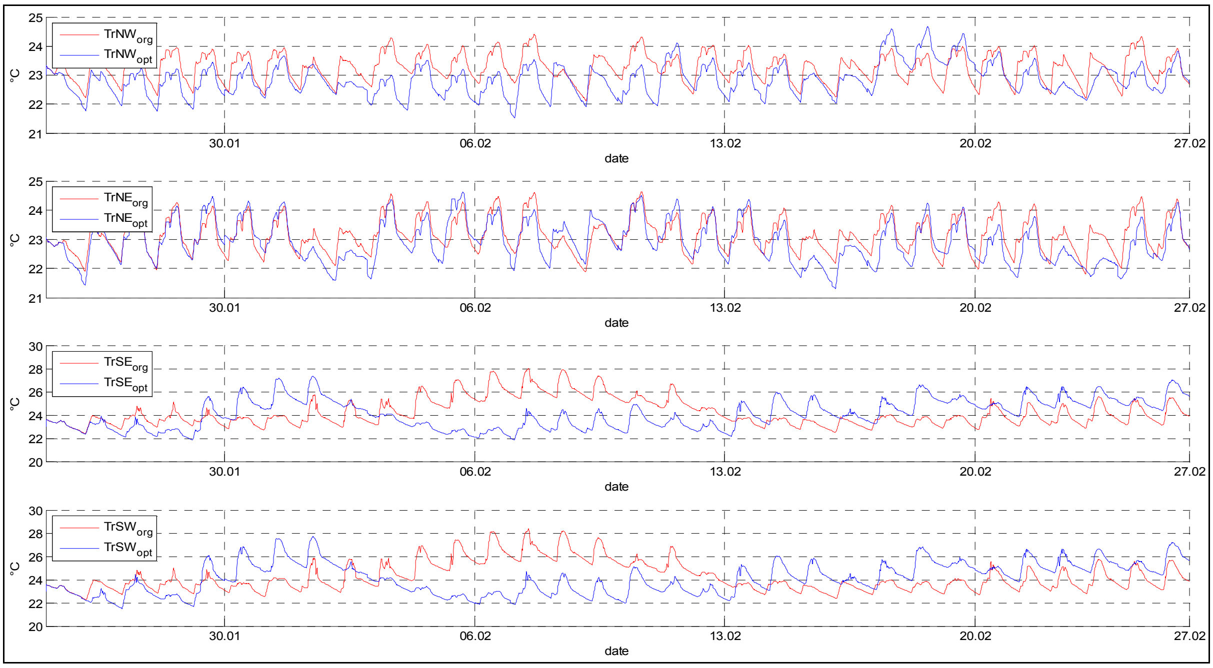

Figure 6: Average room temperatures with ($T_{room,\ opt}$) and without ($T_{room,\ org}$) model-based control

Finally a detailed analysis of the energy saving of the previous mentioned simulation period was made (see table 2). The results show a significant improvement of the thermal energy demand $Q_{Flow,\ Heating}$ needed for the heating system which is about 20% saving. Corrected by losses through the building shell, the total saving concerning thermal energy is about 12%. Focusing on electrical energy saving of the heat pumps only, about 7% electrical energy can be saved by applying the developed model-based control algorithm. It is less compared to the thermal energy saving because the heat pumps supplies also remaining equipment with thermal energy constantly.

Table 2: Energy savings by applying model-based control

$Q_{Flow,\ Heating}$	Heat pump electric energy	$Q_{Flow,\ Heating}$ corrected by losses
-19.73%	-6.83%	11,49%

Conclusion and Outlook

As shown, model-based- control of a large and quite complex building is already possible. This paper discussed a methodology for the possible implementation of a model-based controller in conjunction with optimization into an existing office building. Furthermore possible savings of thermal energy ~20% and electrical energy ~7% used for heating could be identified using a simulation study of the building to be controlled.

The use of simplified models, which were calibrated using data from a detailed simulation model in a conventional thermal modelling tool, was quite feasible, but the need for such a model still is a drawback. The creation of such complex thermal models is always large in terms of time and personal, and the cost may outweigh the improvements made to the control strategy. The limitations for the actual implementation of such algorithms are the building automation systems themselves, which often need excessive retooling to be able to accept the amount of changes in set-points etc.

requested by MPC systems, as well as the computational power needed, which is often not available in the hardware the systems are running on.

Still a lot of these limitations can be solved, and will be dealt with in future work. The need for a detailed model can be eliminated by calibrating the model using monitoring data. Together with the use of cloud computing infrastructure, which allows the use of more computation power and repeated calibration of the RC models, allowing to take into account a change in the usage of the building. This also makes the computational power needed cheaper, and allows the shift of investment costs to running cost when creating or improving building automation systems, dramatically increasing the potential gains – both in terms of energy savings as well as financial gains. Emerging open BEMS systems, like the OGEMA framework, start to become actual alternatives to the commercial systems available, and hope will be strengthened by the possibility of easily implementing MPC on these platforms, and vice versa.

Acknowledgments

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A Fault Detection and Diagnosis Framework for Application at Airports

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Abstract

The objective of the European project "CASCADE – ICT for Energy Efficient Airports" is to develop an ISO 50001 conform Energy Management System (EMS) supported by automated Fault Detection and Diagnosis (FDD) for heating, ventilating, air-conditioning and refrigeration systems (HVAC&R) and to implement and test it at two major European airports, Milano Malpensa and Roma Fiumicino. FDD aims to recognize faults quickly, systematically and possibly automatically before too much energy is wasted. For this purpose we developed a FDD framework that unifies multiple approaches into one common interface.

Two main approaches for fault detection are pursued at the airports: rule-based and qualitative model-based. These two approaches have complementary features which make them a good choice for an overall framework.

For the use at the airports, the FDD results can be accessed from the CASCADE solution via a web interface, which was developed dedicatedly for this purpose. This allows the users at the airports to quickly identify and thus remedy a failure in any of the targeted systems of the airport. In this solution the framework utilizes additional data from an airport ontology and integrates FDD results from a consortium partner into the visualization.

Introduction

Large amounts of energy (up to 30%) are currently wasted in commercial buildings due to insufficient maintenance, faulty equipment or wrong schedules of control loops setup. A significant part of this energy could be saved by the practical implementation of automated Fault Detection and Diagnosis (FDD) to support a condition-based maintenance [1]. The reasons for the lack of broad implementation and market penetration of FDD systems are also caused by a range of general and technical barriers, which have been already identified in former studies, like in [2].

Airports can be seen as one example where FDD in buildings can have an especially high impact. They are responsible for a considerable amount of energy needs and CO_2 emissions: the typical electricity consumption of an airport is 100 – 300 GWh per year, which is as much as 30,000 to 100,000 households consume. Such high energy consumption is partly due to poor performance of energy systems like chillers, heating and cooling circuits, air handling units (AHU) and lighting systems. Current Building Automation Systems (BAS) and Building Management Systems (BMS) have the capacity to integrate a lot of heterogeneous components, but in the majority of the cases they are not designed to perform a detailed energy monitoring by detecting energy related faults and system malfunctions leading to energy losses.

CASCADE[1] will develop a measurement-based, technology neutral, fault detection approach for the development of ICT solutions that can be integrated in Building Automation and Management Systems to develop facility-specific operational guidelines for the reduction of energy consumption (20%) and CO2 emissions (20%) of EU-27 Airports.

To this end fault detection aims to recognize faults quickly, systematically and – as far as possible – automatically before additional damage to the system occurs, before the system fails or before too much energy is wasted. To allow easy integration of different FDD approaches and interaction with the different other components in the CASCADE solution a FDD framework has been developed.

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[1] http://www.cascade-eu.org

Framework Description

This part of the paper describes the overall concept of the FDD framework, the main analysis routines with a focus on the integration of the different parts to the system.

Data Acquisition and Handling

To realize a robust FDD system, high quality of the used measurement data is of paramount importance. Thus, the framework relies on the DataStorage tool developed at Fraunhofer ISE for data handling (see also [3]). The tool provides a secure and efficient way to store the arising time series data through an hdf5 database and offers several routines for sampling and preprocessing of the data. DataStorage has been used in several other projects and is thus thoroughly tested (e.g. [2]). The described FDD routines were designed to be integrated into DataStorage and augment its functionality as depicted in Figure 1.

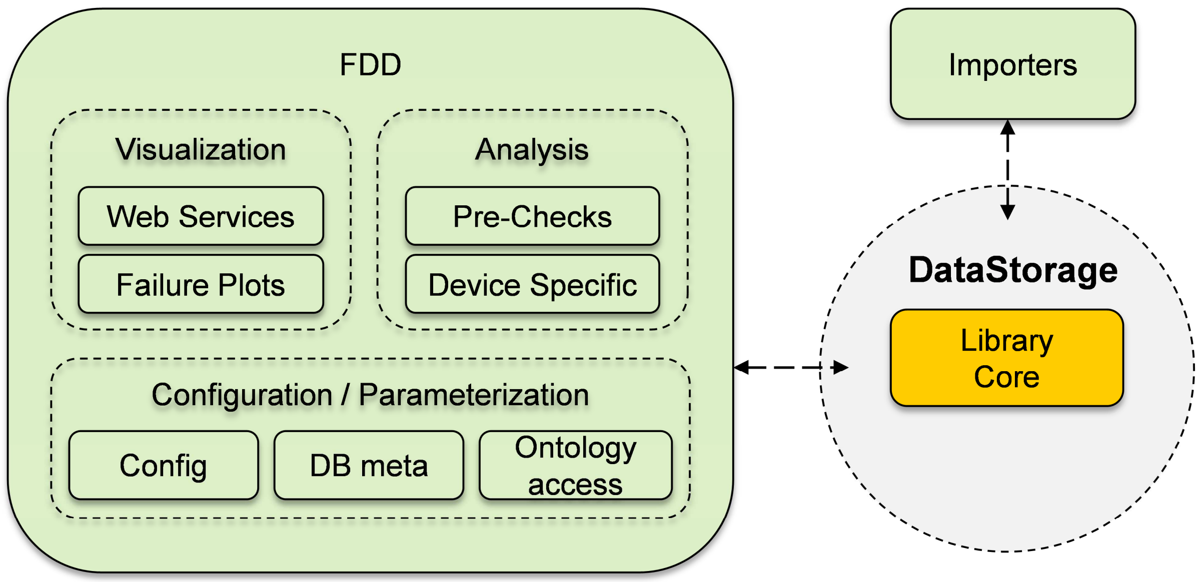

Figure 1 FDD integration to the DataStorage data handling tool

The FDD routines are integrated into the DataStorage tool in the same way as the already existing components for statistical analysis, data import or pre-processing.

One part of the used data is based on the installed data points used by the BMS (see Figure 1). The data is gathered directly through the BACnet protocol [4], stored at a local data server and routinely synchronized to the DataStorage server for import[2]. Using the BACnet protocol, one circumvents accessing trend data of the typically proprietary BAS.

In order to further enhance the data quality in CASCADE, additional data loggers were installed to complement the data points already incorporated by the airports BMS. These advanced data loggers[3] allow for high quality of the gathered data. They can be accessed through a software interface especially designed for the usage with DataStorage and thus facilitate the import of the data to the database.

Each data point delivering measurements is mapped to a data point name in the database. The use of a unified data point naming convention assures that these data point names are unique throughout

[2] The access is realized through dedicated tools of the consortium partner Sensus MI

[3] Integrated by the consortium partner PSE

the addressed systems while guaranteeing that analysis routines can fetch the correct data for a system component by using generalized patterns.

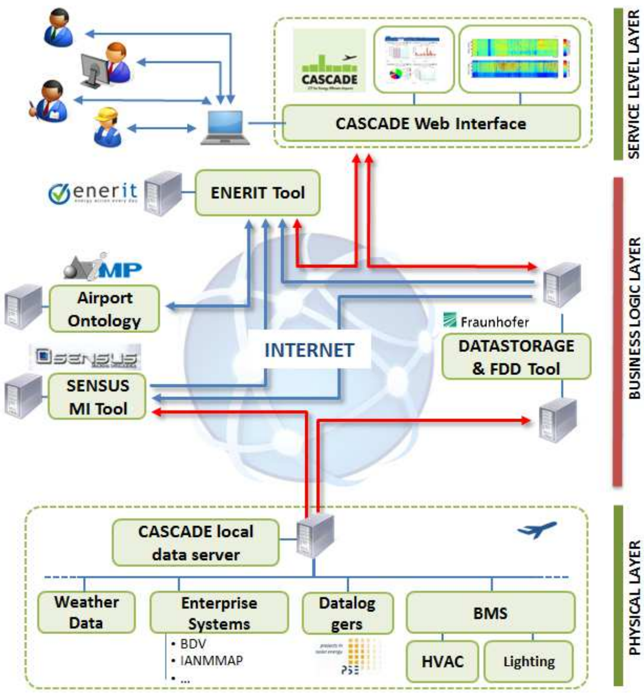

Figure 2 Data transfer in the CASCADE solution

The data measured at the airports BMS is gathered and transferred to the CASCADE data server alongside the data from the advanced data loggers. The data is routinely synchronized with the DataStorage server for import to the database. In the application for the ISO 50001 compliant CASCADE EMS the visualization of the FDD results gets enriched through additional information from the airport ontology and a second FDD tool. (image source: [5])

Fault Detection Routines

The described FDD framework is thought to combine different FDD routines within one generic interface. By utilizing the unified data point naming convention of the underlying DataStorage tool the FDD routines were designed to analyze failures in different buildings and systems without extensive adoption. Therefore, the needed measurement data for the analysis routines is defined by appropriate generic patterns.

Up to now the work focused on the implementation of analysis routines for water circuits, AHU units and chillers. In the developed FDD framework realizations of these units are responsible for managing the different analysis routines and for gathering the needed data. The order of the analyses is structured from simple signal based routines to more complex ones, which employ further insight into the system.

Since qualitatively good measurements are crucial to ensure the reliability of the applied FDD methods, inaccurate or incorrect measurements can automatically result in poor performance of the FDD methods generating false alarms and incomplete detections. Therefore, before processing the data by the system specific FDD routines, a first validation step of sensor data is carried out. This step ensures that the data used for the more complex routines is actually valid. Otherwise, the following analyses might accidentally identify failures on a system scale, while the actual fault resides in the input data, stemming from erroneous sensor operation.

When the signals of the sensors are verified to be valid for the time range under investigation, simple rule based checks of the system operation are performed. In this step the basic system operation is verified, e.g. by comparing component operation schedules and actual operation indicators. A majority of failures in building automation systems is due to wrong implementations of operation schedules. If these basic guidelines are not fulfilled, operation times can exceed the actually needed time span, which directly leads to increased energy consumption. Additionally, operation outside of the planed time ranges can be indicator for further failures due to malfunctioning sensors or wrong orchestration of system interoperations. Inside the described FDD framework, schedule detection is implemented as a system specific signal based analysis. This attempt does not facilitate deep insight into the systems operation principles, but uses simple sensor and signal data as indicators for the systems operation. As an example, if there are no additional signals indicating the operation of an AHU, the power consumption of its fans can be used as a valid source to investigate the systems operation. Changes in the corresponding sensor data are detected using signal analysis algorithms and the times for start and end of the systems operation are extracted. This information can then be checked against the schedules as specified in the systems guidelines or against existing signals indicating the systems operation.

After checking for sensor faults and basic plausibility checks of the system operation, a pre-classification step is performed to determine the operation mode, where needed, for later analyses. Besides of specifying the remaining analysis steps, this mode can also be compared to the operation mode as given by the control signals of the unit. If these modes do not match or there are inconsistencies among the determined operation modes, a failure can be identified.

Most of the actual rule based analysis is performed at the end of the overall procedure. The two major implemented analysis methods are a rule based and a qualitative modelling (QuaMo) approach. In the rule based approach, different sets of device specific rules are used to check for a consistent state at a certain time step. The rules used for this analysis are based on simple thermodynamic and energy conservation rules (cf. [6]). Each rule is realized as a single specialization of a base analysis of the rule system. This specialization bundles all necessary information for the rule to be checked, like the needed input data or the algorithm for checking the rule. The second major part of the implemented FDD routines is given by the qualitative modelling approach (see also [7, 8]). This approach utilizes a stochastic automaton to describe the qualitative behavior of the analyzed system. The automaton is trained beforehand, either with data from a quantitative simulation model or directly with baseline measurement data. In case of simulated data the training may also include faulty behavior to ease diagnosis on the results.

Visualization of Results

To allow the airport staff to quickly identify possible energy saving potentials, an online tool for visualizing the FDD results has been developed. The web application is embedded in a specific view in the ISO 50001 EMS[4] and provides an interface to the EMS for importing FDD results.

When accessing the FDD visualization, one can first access an overview plan for the airport site. The view gathers some information about the number of detected failures in the different subsystems and thus allows a quick overview of the overall failure status. Furthermore, one can access an alarm handling page for the airport site.

The main components for the visualization are the overview plans of the different systems. The schemes show icons for the different sensors, corresponding to the data stored in the database. For this purpose, a mapping of unified data point names to visual output elements on the system schemes has been applied. The interactive scheme view provides further details of the sensors. Since not all sensors used for the analyses may also be of interest for the general overview of the system, not all sensors are shown from the beginning. Some sensors are only shown, when an appropriate failure is selected from a list of found failures. The visualization component is designed to have a loose coupling to the major FDD part, also allowing the integration of FDD results from other sources[5].

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[4]Developed by the consortium partner Enerit

[5] In case of the CASCADE project the FDD results of consortium partner Sensus MI are also visualized.

Besides the system overview plan with the schematic view, there are further views, which give access to plots of the sensor data and the detected failures.

Configuration and Parameterization

There are several ways for configuration incorporated in the described FDD system. The most basic one is the usage of database metadata stored for each data point. This metadata gives access to additional information, such as measurement units and value boundaries for the stored sensor data. Also the used data point naming convention can be used to deliver an essential configuration of the analysis routines to match the given circumstances. Further details, like dependencies between the different systems and components, are typically manually added through a configuration file. In the CASCADE project, this manual configuration can partly be replaced by utilizing the data stored in the CASCADE solutions airport ontology[6] (see also [9]). Apart from additional metadata about the different airport systems, the ontology also stores information about relations between the different systems and system components, which can be used to obtain the needed data for FDD. Furthermore, the data from the ontology can be used to enrich the information shown in the FDD visualization.

Application

Currently, first tests for applying the FDD framework to the data of the CASCADE pilot airport Rome Fiumicino are conducted. At the second pilot, airport Milano Malpensa, there are still installations to be concluded. The process of performing the needed installations at both airports was lengthened by obstacles often encountered in such kind of projects and which have been pointed out before [2]. Since CASCADE aims at delivering a way to replicate the solution to all European airports, these experiences have been included in the projects methodology. Thus, future endeavors on incorporating FDD at airports will be able to circumvent such problems.

Conclusion and Outlook

We present a fault detection and diagnosis framework that incorporates all major components that are needed for its application at airports – from data handling to FDD visualization. In the context of the European CASCADE project the framework got successfully embedded in the overall CASCADE solution using data from the BMS, additional data loggers and an airport ontology to allow a FDD enabled ISO 50001 compliant energy management.

Future work will be centered on the usage of the framework at the both CASCADE pilot airports and the validation of the overall methodology. This may also allow a comparison of the different FDD approaches and an evaluation of the benefit of the additionally installed measurement equipment at the airports.

[6] Developed by the consortium partner Institut Mihajlo Pupin.

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