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IMPROVING ENERGY EFFICIENCY IN COMMERCIAL BUILDINGS

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IEECB'06

Frankfurt, Germany, 26 - 27 April 2006

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European Commission, DG JRC,
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VOLUME 1

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The mission of Institute Environment and Sustainability is to provide scientific and technical support of EU policies for protecting the environment and the EU Strategy for Sustainable Development.

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Introduction

The commercial buildings sector is one of the fastest growing energy consuming sectors. This is mainly due to the growth of commercial and public activities and their associated demand for heating, cooling ventilation (HVAC) and lighting. Moreover in the new economy, with a wide dissemination of information and communication technologies, information technology equipment is also an important source of electricity consumption. For the tertiary sector space heating is responsible for about 50 % of total consumption of the sector, while energy consumption for lighting and office equipment and "other" (which is mainly office equipment) are 14% and 16%, respectively.

In its Green Paper on energy efficiency, the European Commission (EC) called for concrete measures to reduce growth in energy demand, mainly by promoting energy saving in buildings and the transport sector. According to the EU Green Paper, energy use in buildings could be reduced by at least a fifth by making greater use of available and economically viable energy-efficient technologies. This would represent about 20% of the EU's greenhouse gas reduction commitment. Such savings would also improve the energy supply security and the EU's competitiveness, while creating job and raising the quality of life in buildings.

Greenhouse gas reduction is a common denominator of many countries' environmental policies and programmes. The European Union's Climate Change Programme showed that Europe can meet and surpass its reduction targets while at the same time save money and improve productivity. Commercial buildings are a key area where the ECCP programme can, and must be realised, since it makes economic sense for the building owners and occupiers. As a consequence of the EU commitment to comply with the Kyoto targets, all actors need to take all necessary steps to disseminate good practice, foster investment in energy efficiency and provide technical solutions for the commercial building sector. Other regions of the world are also exploring potential programme and policy options to reduce commercial building energy waste.

Not only is every kWh saved avoiding pollution and CO2 emissions, but it is also reducing peak power requirements; a problem common to many countries. That is the reason why every achievement in the field of demand-side management (DSM), or more generally the improvement of energy efficiency has a direct effect on greenhouse gas emission reduction and on the security of energy supply. The European Directive on the Energy Performance of Buildings will require a major effort to improve building energy performance and will bring the energy performance of their buildings to the forefront of building market operators. This simultaneously presents an opportunity and challenge for energy efficiency.

The recent liberalisation of the electricity and gas markets could be an additional opportunity in the development of these efforts, as the competition eventually developing between the key players in the electricity and gas industry will not be focused only on prices but also on the service. In the long term there is the possibility that energy services and renewable energy sources (RES) would enable greater differentiation among utilities, Energy Service Companies (ESCOs), etc. Many property managers are now offered the services of ESCOs and facility management companies to manage and reduce the energy consumption in their buildings. A number of local, regional and national policies and programmes have recently been implemented to achieve a long lasting market transformation. The proposal for a Directive on energy efficiency and energy services shall further contribute to the establishment of an energy efficiency market.

Low consumption commercial (office) buildings have been constructed and operated in the EU and they have proven that it is feasible to reach low consumption targets. There are some very good examples of low consumption commercial (office) buildings, especially in Germany. A major result is, that the reduction of consumption of primary energy is not only some percent, but new buildings have reduced consumption by a factor of 3 to 4 !

In many cases low energy office buildings have lower investment cost than conventional ones, especially where supply efficiency can be integrated or natural cooling is used. Where the initial cost of the efficient is greater than the normal market practise, these additional investment costs invariably turn out to be economical within the expected lifetime of the buildings, even on the assumption of constant energy pricing, a totally unrealistic assumption.

Furthermore energy efficient building owners and investors are happy. There is growing evidence on both sides of the Atlantic that the occupiers in high-efficiency buildings are happier, and significantly more productive. The value of the productivity normally outweighs the operating savings for the pure energy costs Lower energy costs are combined with a good or even better comfort and substantially increased employee productivity. Thus investors and occupants are both happy with these buildings. The key question is why are such a kind of buildings still an exception and not the standard? And why cost effective building investments and retrofit do not take place.

Following the success of the GreenLight programme the EECO recommended to establish the European GreenBuilding Programme (GBP), covering additional energy end-use technologies in addition to lighting. The GBP is a new voluntary programme started in early 2006. It is meant to help overcome some of the barriers to energy efficiency - in particular the lack of interest and information - by providing public recognition and information support to companies and public organisations whose top management is ready to show actual commitment to adopting energy efficient measures in buildings.

Following the success of the previous IEECB conferences (IEECB'98 in Amsterdam, IEECB'02 in Nice and IEECB'04 in Frankfurt) Messe Frankfurt with the scientific collaboration of the European Commission Joint Research Centre organised the fourth International conference on Improving Energy Efficiency in Commercial Buildings (IEECB'06) in conjunction with the Building Performance Congress (www.bp-congress.de). The IEECB'06 conference took place on 26 and 27 April 2006 in Frankfurt during Light+Building, the International Trade Fair for Architecture and Technology in Frankfurt, Germany.

The IEECB conference brought together all the key players from this sector, including commercial buildings' investors and property managers, energy efficiency experts, 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.

At the conference key representatives of leading organisations and companies, institutions and equipment industry presented the overall picture and give details of policies, recent advancements and examples of best practice.

The wide scope of topics covered during the IEECB'06 conference included: macro/micro approaches, state-of-the-art 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 R&D, tools, regulation & policy, demand-side and supply-side perspectives for all branches of activity (public and private sector, the commerce and retail sectors, hotels and restaurants, banks and insurance companies, local authorities, civil services & public bodies, education, universities & laboratories, hospitals, airport and stations, etc.)

We hope that the present proceedings could be a valuable contribution to disseminate information and best practices in policies, programmes and technologies to foster the penetration of highly efficient buildings in the commercial sector.

The Editors

Paolo Bertoldi
Bogdan Atanasiu

International Conference on
Improving Energy Efficiency in Commercial Buildings
IEECB'06
Frankfurt, 26-27April 2006

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22. Gerald Strickland, ELC
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Fourth International Conference
Improving Energy Efficiency in Commercial Building
(IEECB'06)

Frankfurt, 26-27 April 2006

Organised by Messe Frankfurt with the scientific co-operation of the European Commission DG JRC
During the International Building Performance Congress for Architecture and Technology (24 – 27 April 2006) at
the Light+Building International Trade Fair for Architecture and Technology 23 – 27 April 2006 Frankfurt am Main

IEECB'06
Improving Energy Efficiency in Commercial Building Conference 2006

Wednesday, 26 April 2006

Location: Congress Center Messe Frankfurt (CMF)

Time	Lighting ***Chair*: Gerald Strickland** ***European Lamp Companies Federation (ELC), Brussels, Belgium***	Energy Service Companies (ESCO) ***Chair*: Ralf Goldmann** ***Berliner Energie Agentur, Berlin, Germany***
	CMF, Room Harmonie 1	CMF, Room Harmonie 2
10:00	**Development of an international roadmap for daylighting design** *Steve Coyne, Applied Optics Group, Science Research Centre, Queensland University of Technology, Brisbane, Australia* **The challenges of getting new, integrated daylighting systems into commercial buildings** *Stephen Selkowitz, Lawrence Berkeley National Laboratory, Berkeley, USA* **Lighting in Call Centres** *Paul Bannister, Exergy Australia Pty Ltd., Belconnen, Australia* **Best practice for lighting in Frankfurt schools also standard in the directive with 2W/(m2 100lx)** *Axel Bretzke, City of Frankfurt, Dep. Energy Management, Frankfurt/Main, Germany* **The implementation of energy-efficient lighting in Flanders: "Groen Licht Vlaanderen"** *Catherine Lootens, Groen Licht Vlaanderen, Gent, Belgium* **The results of the GreenLight Programme and the extension in the new EU Member States and Candidate Countries** *Paolo Bertoldi, European Commission DG JRC, Ispra, Italy*	**Risk Assessment in Efficiency Evaluation** *Paolo Bertoldi, European Commission DG JRC, Ispra, Italy* **Contracting in German state properties** *Jens Gröger, Deutsche Energie-Agentur GmbH (dena), Berlin, Germany* **Internal performance commitments** *Wolfgang Irrek, Wuppertal Institut für Klima Umwelt Energie GmbH, Wuppertal, Germany* **Comparison of different finance options for energy services** *Jan W. Bleyl, Graz Energy Agency Ltd, Graz, Austria* **Promoting energy efficiencies : recent development of ESCO industry in Singapore and development of the local M&V protocol in Singapore** *Majid Haji-Sapar and Qu Qing, Energy Sustainability Unit, Department of Building, School of Design and Environment, National University of Singapore, Singapore* **Private Investments Move Ecopower (PRIME) – A participatory. approach to financing energy efficiency measures** *Bettina Wittneben, Wuppertal Institut für Klima, Umwelt und Energie GmbH, Wuppertal, Germany*

IEECB'06
Improving Energy Efficiency in Commercial Building Conference 2006

Wednesday, 26 April 2006

Location: Congress Center Messe Frankfurt (CMF)

Time	Renewable Energy Sources (RES) *Chair: Jerome Adnot* *Centre for Energy and Processes, Ecole des Mines de Paris, Paris, France*	Investments *Chair: Jacky Pett* *Association for the Conservation of Energy, London, UK*
12:00	*Lunch break*	*Lunch break*
13:00	**Techno-economic viability of an advanced cogeneration system integrated in a low energy demand public building** *Joan Carles Bruno, Universitat Rovira i Virgili, Tarragona, Spain* **SOLITEM - Solar cooling systems based on SOLITEM Parabolic through collector PTC 1800 combined with double effect absorption chillers** *Ahmet Lokurlu, SOLITEM GmbH, Aachen Germany* **A new project of the International Energy Agency: "Heat pumping and reversible air-conditioning"** *Jean Lebrun, University of Liège, Liège, Belgium* **Wind catchers: Improving the operating performance for wider applicability** *Farzad Jafar Kazemi, Mechanical Engineering Department, Faculty of Engineering, Islamic Azad University,South Tehran Branch, Tehran, Iran*	**Investors' motivation towards green buildings** *Susanne Geissler, University of Natural Resources and Applied Life Sciences, Vienna, Austria* **"Green buildings" – investment benefits** *Ashak Nathwani, Norman Disney & Young, Sydney, Australia* **Making invisible property investments attractive** *Rick Wilberforce, EuroACE, St. Helens, UK* **Integral planning of energy efficiency, cost and comfort – a comprehensive cost and benefit evaluation** *Martin Jakob, Centre for Energy Policy and Economics (CEPE), Zurich, Switzerland*

IEECB'06
Improving Energy Efficiency in Commercial Building Conference 2006

Wednesday, 26 April 2006

Location: Congress Center Messe Frankfurt (CMF)

14:30	***Coffee break***	***Coffee break***
Time	**Heating, Ventilation, Air-Conditioning** ***Chair*: *Jean Lebrun*** ***University of Liège, Liège, Belgium***	**Energy Performance of Buildings Directive (EPBD)** ***Chair*: Gordon Sutherland** ***European Commission, Intelligent Energy Executive Agency, Brussel, Belgium***
14:45	**Experimentation of the CEN standard on the inspection of air-conditioning systems** *Maxime Dupont, Centre for Energy and Processes, Ecole des Mines de Paris, Paris, France* **Energy pumping concepts to address simultaneously occurring cooling and heating demands in air-conditioned buildings - status quo, comparative analyses and design potentials** *Evgenia Sikorski, University of Applied Science Offenburg, Bochum, Germany* **Selection of procedures for air conditioning audit and definition of the associated training package** *Daniela Bory, Centre for Energy and Processes, Ecole des Mines de Paris, Paris, France* **Customer advising with help of documented case studies and of benchmarks; modelling and simulation for adaptation of benchmarking in HVAC** *Philippe André, University of Liège, Arlon, Belgium*	**Applying LEED® Internationally: progress and lessons learned** *Sabrina Morelli, U.S. Green Building Council, Washington, USA* **EPLABEL: a graduated response procedure for producing a building energy certificate based on an operational rating** *Robert Cohen, Energy for Sustainable Development, UK* **Empirical benchmarking of building performance** *Paul Bannister, Exergy Australia Pty Ltd., Belconnen, Australia* **EPA-NR, tools for the assessment of the Energy Performance of Non-Residential Buildings in the European countries** *Bart Poel, EBM-consult, Arnhem, The Netherlands*

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Improving Energy Efficiency in Commercial Building Conference 2006

Wednesday, 26 April 2006

Location: Congress Center Messe Frankfurt (CMF)

16:15	***Coffee break***	***Coffee break***
Time	**Heating, Ventilation, Air-Conditioning** ***Chair*: *Paul Bannister*** ***Exergy Australia Pty Ltd., Belconnen, Australia***	**Energy Performance of Buildings Directive (EPBD)** ***Chair*: *Peter Wouters*** ***BBRI, Brussels, Belgium***
16:30	**National and EU wide efforts to increase energy efficiency of installed air-conditioners** *Jerome Adnot,* **,** *Centre for Energy and Processes, Ecole des Mines de Paris, Paris, France* **Measured Building and AC System Energy Performance: An empirical evaluation of the energy performance of air-conditioned office buildings in the UK** *Gavin Dunn, Association of Building Engineers, UK* **Effect of the certification on energy management** *Yamina Saheb, EUROVENT, Paris, France* **The U.S. Energy Policy Act of 2005 and its impact on commercial air-conditioning and refrigeration equipment** *Karim Amrane, Air-Conditioning and Refrigeration Institute, Arlington, USA*	**Will the Energy Performance of Buildings Directive make any difference to commercial sector emissions?** *Jacky Pett, Association for the Conservation of Energy, London, UK* **B.E.A. (Building Energy Analysis) - a methodology for energy certification in buildings. A practical example for a small hospital** *Francisco Javier Rey, Thermal Engineerig. Scool of Industrial Engineering, University of Valladolid, Valladolid, Spain* **Certification of non-residential buildings: results of dena field test on procedures and user-acceptance** *Christina Sager, Deutsche Energie-Agentur GmbH (dena), Berlin, Germany* **The seasonal efficiency of multi-boiler and multi-chiller installations** *Roger Hitchin, BRE Environment, Watford, UK*
18:00	***End of First day***	

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Improving Energy Efficiency in Commercial Building Conference 2006

Thursday, 27 April 2006

Location: Congress Center Messe Frankfurt (CMF)

Time	**Monitoring** ***Chair*: Martin Jakob** ***Centre for Energy Policy and Economics (CEPE), Zurich, Switzerland***	**Examples** ***Chair*: Benke Georg** ***Austria Energy Agency, Vienna, Austria***
	CMF, Room Harmonie 1	CMF, Room Harmonie 2
10:00	**Awareness activities for energy efficiency in the commercial and public sector : learning from success stories to disseminate good practices** *Jean-Sébastien Broc, Ecole des Mines de Nantes (DSEE), Nantes, France* **Energy consumption metering, monitoring and benchmarking** *Cui Qi, Department of Building,School of Design & Environment, National University of Singapore, Singapore* **Energy efficiency in commercial buildings – experiences and results from the German funding program SolarBau** *Sebastian Herkel, Fraunhofer-Institute for Solar Energy Systems, Freiburg, Germany* **EVA – Evaluation of energy concepts for office buildings** *Stefan Plesser, IGS – Institute for Building Services and Energy Design, Technical University Braunschweig, Braunschweig, Germany* **Mining corporate sustainability reports for building energy performance data** *Adam Hinge, Sustainable Energy Partnerships, Tarrytown, USA* **Intelligent energy and water performance assessment in municipal buildings** *Paul Fleming, Institute of Energy and Sustainable Development, Leicester, UK*	**Examples of advanced/demonstration buildings** *Anita Preisler, Arsenal research, Vienna, Austria* **Integrated evaluation of buildings for energy efficiency: a case study in office buildings** *Efrossini Giama, Aristotle University of Thessaloniki, Thessaloniki, Greece* **"Reality Check" organised by the competence network innovative building services engineering (KinG): the case Uniqa Tower Vienna** *Susanne Gosztonyi, Arsenal Research, Vienna, Austria* **Incorporating energy in facility management experiences of the Dutch ministry of defence** *Bart Poel, EBM-consult, Arnhem, The Netherlands* **European Energy Trophy** *Theresa Glasmacher, B. & S.U. Beratungs- und Service-Gesellschaft Umwelt mbH, Munich, Germany* **Sustainability in the frame of the Turin Olympic Village: tools for the environmental building design** *Roberto Pagani, Politecnico di Torino Torino, Italy,*

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Thursday, 27 April 2006

Location: Congress Center Messe Frankfurt (CMF)

12:00	***Lunch break***	***Lunch break***
Time	**Heating, Ventilation, Air-Conditioning** ***Chair*: *Paul Waide*** ***International Energy Agency, Paris, France***	**Policy** ***Chair*: *Paolo Bertoldi*** ***European Commission, DG JRC, Ispra, Italy***
13:00	**Impact of climate change on energy demand in the commercial / service sector** *Bernard Aebischer, Centre for Energy Policy and Economics (CEPE), Zurich, Switzerland* **Adaptation of commercial buildings to hotter summer climates in Europe** *Conrad U. Brunner, A + B International, Zurich, Switzerland* **Air-conditioning surveys in the UK retail sector or "Keeping the Cold in"** *Neil Brown, Research Fellow, Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK* **The Components of Heating and Cooling Energy Loads in UK Offices, With a Detailed Study of the Solar Component** *Andrew Marsh and Ian Knight, Welsh School of Architecture, Cardiff, UK*	**GreenBuilding: Enhancing the Energy Efficiency of Non-Residential Buildings** *Annegret-Claudine Agricola, Deutsche Energie-Agentur GmbH (dena), Berlin, Germany* **The Austrian program for private service buildings: ecofacility** *Margot Grim, Austrian Energy Agency, Vienna, Austria* **Beyond energy efficiency: How the USGBC and LEED are driving market transformation** *Andrea Pusey, U.S. Green Building Council, Washington, USA* **Innovative commercial buildings in Upper Austria** *Christiane Egger, O.Ö. Energiesparverband, Linz, Austria*

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Location: Congress Center Messe Frankfurt (CMF)

14:30	***Coffee break***	***Coffee break***
Time	**Heating, Ventilation, Air-Conditioning** ***Chair*: *Roger Hitchin*** ***BRE Environment, Watford, UK***	**Policy** ***Chair*: *Bill Bordass*** **William Bordass Associates, London, UK**
14:45	**Reducing cooling energy demand in commercial buildings** *Márton Varga, Austrian Energy Agency, Vienna, Germany* **Field testing of several CO2/presence based Demand-Controlled Ventilation techniques within six different tertiary sector buildings** *Nancy Nicholson, Elyo Cylergie, Ecully, France* **Sizing and instrumentation of a solar-desiccant cooling system in the East of France** *Dominique Marchio, Center for Energy and Processes, Ecole des Mines de Paris, Paris, France* **Gas Heat Pumps (GHP) reduce energy consumption of buildings** *Thorsten Formanski, ASUE – Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch e.V, Essen, Germany*	**Australia's path to energy efficiency in commercial buildings – regulation, rating tools and market approaches** *Stephen Berry, Australian Greenhouse Office, Canberra, Australia* **Study on the incentive policies to promote China's building energy efficiency** *Kang Yanbing, Energy Research Institute, National Development and Reform Commission, Beijing, China* **Energy-efficiency regulations and better design practices in new commercial buildings in Mexico** *Odón de Buen, Facultad de Ingeniería, Universidad Nacional Autónoma de México, México* **High-Performance Buildings in the US: Beyond energy code-based models for supporting premium efficiency in commercial buildings** *Brian McCowan, Energy & Resource Solutions, Inc., Haverhill, USA*

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Location: Congress Center Messe Frankfurt (CMF)

16:15	***Coffee break***	***Coffee break***
Time	**Office Equipment and Lighting** ***Chair*: *Silvia Rezessy*** ***Central European University, Budapest, Hungary***	**Simulation** ***Chair*: *Adam Hinge*** ***Sustainable Energy Partnerships, Tarrytown, USA***
16:30	**Current and future energy demand of ICT appliances in offices – a recent assessment for Germany** *Barbara Schlomann, Fraunhofer Institute Systems and Innovation Research, Karlsruhe, Germany* **ELC actions to promote efficient lighting in the professional sector** *Gerald Strickland, European Lamp Companies Federation (ELC), Brussels, Belgium* **Commercial building lighting energy use: an in-depth global assessment of lighting service, energy consumption, savings and potentials** *Paul Waide, Energy Efficiency and Environment Division, International Energy Agency, Paris, France* **Lighting in commercial buildings: a global review of existing efficiency policies and the potential for them to be strengthened** *Paul Waide, Energy Efficiency and Environment Division, International Energy Agency, Paris, France*	**A decision support model using expert knowledge for building energy management** *Haris Doukas, Management & Decision Support Systems Laboratory, Department of Electrical and Computer Engineering, National Technical University of Athens, Athens, Greece* **Thermal performance and sustainability assessment of a health building in a maritime climate – A case study in Sheffield, UK** *Hasim Altan, The University of Sheffield, Sheffield, UK* **Operation diagnostics – a methodology for enhanced building operation** *Oliver Baumann, Ebert-Ingenieure München, Munich, Germany* **Modelling buildings for energy use: A study of the effects of using multiple simulation tools and varying levels of input detail** *Clarice Bleil de Souza, Welsh School of Architecture, Cardiff, UK*
18:00	***End of Conference***	

building
performance
congress

The Challenges of Getting Integrated Daylighting Systems into Commercial Buildings

Stephen Selkowitz[1], Steve Coyne[2]

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[2] Faculty of Science, Queensland University of Technology

Abstract
Lighting in commercial buildings is typically the largest single primary energy end use and accounts for 30% -50% of the electricity costs and is a contributing factor towards the output of building occupants. The use of daylight in these buildings is generally considered in terms of its potential to reduce the electrical lighting load without the more difficult economical consideration for its impact on other building loads such as cooling and on occupant output. The use of daylighting systems is commonly evaluated in terms of return on investment, in particular pay back period. In countries where primary energy resources are in abundance and electricity supply is relatively cheap, it is, in the first instance, difficult to mount an economic argument to building owners for integrated daylighting systems which have little or no documented operational history. In the United States and Australia these conditions prevail. This paper presents some experiences from these two countries with daylight systems and daylighted buildings in combating the economic argument and the cheap electricity supply issue. Approaches taken in developing and utilizing simulation tools along with full scale mock-up building installations prior to construction of the new building as well as advances in research towards dynamic, integrated daylighting technologies are presented.

Introduction
In the United States and Australia the historic availability of plentiful, low cost energy has driven the standard design features of many commercial buildings. Unlike much of Europe, both countries are characterized by having major population centers in sunny climates with substantial cooling loads, although the U.S. has cold climates as well. Building facades and lighting systems are responsible for very large fractions of the overall energy use in commercial buildings. As one would expect the details vary widely with building size, type and climate.

Primary cooling and lighting energy needs are met almost entirely with electricity. In the U.S. the ability of the electric grid to provide reliable power supplies has been strained over the last few years due continued growth in the commercial building sector. In California the electric system peak demand occurs in the late afternoon on a hot summer weekday. At that time two of the three largest contributors to the mid-afternoon peak loads are lighting and cooling in commercial buildings, both of which are directly influenced by façade design and daylighting systems.

Daylight has always been a design goal in European buildings and the design challenge in predominantly northern and overcast climates has been admit adequate daylight. In climates with significant sunlight such as the U.S. and Australia, the potentials for daylight utilization are greater than in Europe but those benefits come with a potential cost. The impact of solar gain associated with daylight on cooling loads can be large. In fact for a poorly designed façade that does not control solar gain the added energy impacts of cooling can be greater than the electric lighting savings from daylighting. The challenge is therefore to manage the flux entering the space in a manner that maximizes value to occupants (appearance, comfort, daylight, view) and to building owners (energy, demand savings) without incurring negative impacts on each, e.g. glare for occupants, increased energy use or higher peak demand for owners.

Prior studies in the U.S. and Australia have demonstrated that a façade with an effective aperture (% of wall in glass x % visible transmittance) of about .30 can provide adequate daylighting for about

65% of the occupancy hours of typical commercial buildings. To improve views and connections with the outdoors, many modern buildings are now being designed using much higher effective apertures, approaching .60. For structures with these glazing levels it is impossible to “optimize” buildings for good daylighting performance with static glazings alone since sunlight/daylight intensity varies so dramatically and the impacts in highly glazed spaces are magnified. Of course very low transmission glass can be used to control solar gains and glare but this eliminates most daylight benefits and impairs the connection to the outdoors. In “transparent façade” designs we believe that optimal energy efficiency for owners and comfort for occupants requires dynamic, interactive façade systems to actively control solar gain, daylight and glare. Successful solutions require proper technology selection, integration between building systems, and optimized sensing and control strategies. The advantage of such systems is that they are well suited to providing the interior conditions best conducive to optimal work conditions as well as energy efficiency.

The conceptual requirements for such a dynamic system with intelligent controls is shown below in Figure 1.

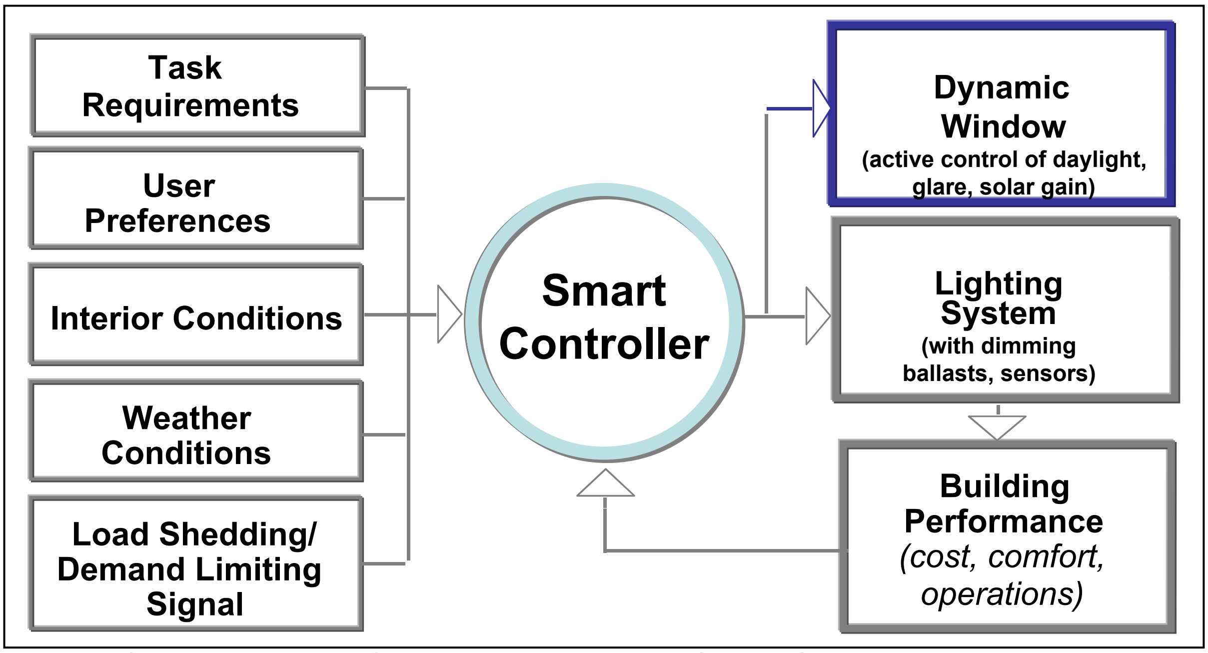
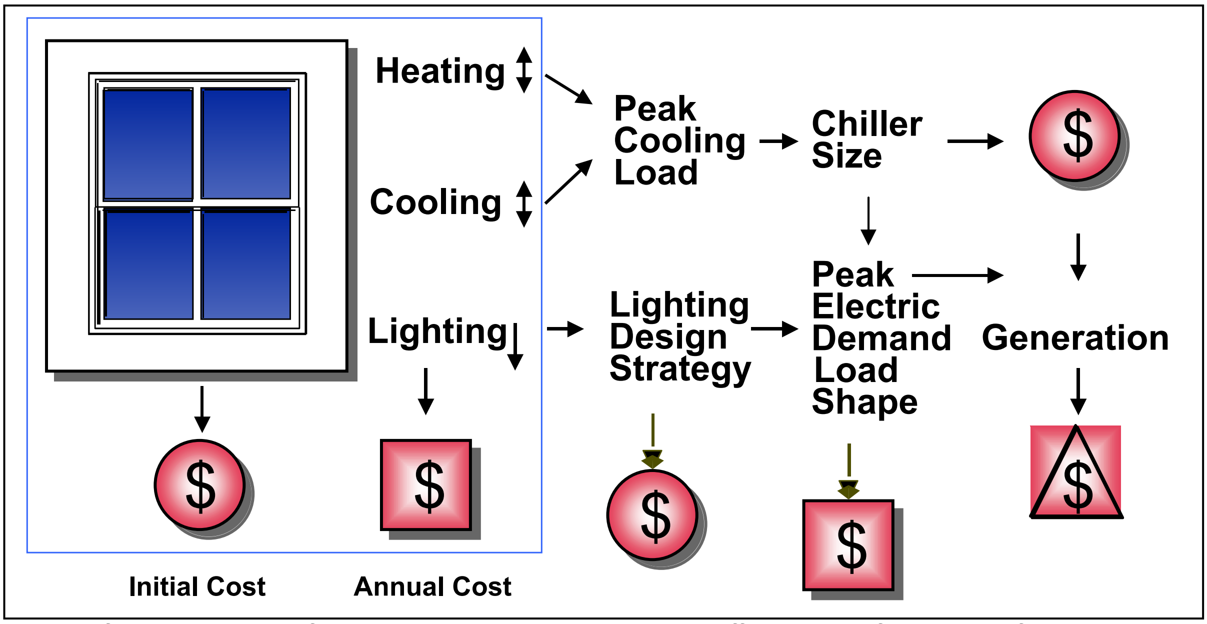


Figure 1: Conceptual Design for a Responsive Façade Control System

The system must be capable of responding to a wide range of seasonal and environmental conditions, user needs and utility rate changes. While the operability and dynamic control might be manually exercised by an occupant or owner, experience to date in the U.S. and Australia suggests that manual control is not sufficiently reliable to generate the consistent savings expected and that the complexity of control to optimize comfort, performance, lighting and cooling may be beyond the intuitive understanding of a typical office occupant. Visual observation in highly glazed buildings suggests for example that electric lights are routinely on even when there is adequate daylight available. Earlier research suggests some occupants will adjust lights or shades when they first enter a room. But they often fail to change the controls as conditions change. Furthermore with many people working in open landscaped spaces and continuously changing conditions one wonders if occupants in many businesses would be expected to spend time tuning the operation of dynamic façade, HVAC and lighting controls. Our research to date suggests that automated systems are preferred for these reasons, assuming that they are properly designed and commissioned, that occupants have some degree of override control, and of course that the solutions are affordable.

Such systems are likely to cost more than conventional static or manually operated systems but there are tradeoffs possible in the overall cost equation. Traditional cost-benefit calculations derive a “payback” from the first cost of solutions and the annual savings for heating, cooling and lighting. A more rigorous and complete analysis would look at the additional first cost of other aspects of fenestration and lighting selection, as shown schematically in Figure 2. The figure shows that the façade design has impacts on the lighting design and the cooling system design, both of which are costly elements in modern buildings. A high performance façade with reliable controls might allow the engineer to reduce the size of the cooling system (chiller and thermal distribution network) to meet a lower peak cooling load than the load from a conventional, non- automated system. In this scenario the added investment in dynamic facades not only generates annual operating costs savings but also



provides first cost savings for the cooling system, which may offset some of the added façade costs.

Figure 2: Building Cost parameters Impacting Façade Investments

Traditional “payback calculations” utilize the initial and annual cost factors in the box at left; a more complete assessment from the perspective of the owner’s cost and societal costs would include the parameters on the right side of the figure as well.

Although much of the final design refinement will be done with computer simulations, for the emerging technology being developed in the U.S. and Australia field tests are desirable to supplement simulation studies to develop smart solutions. In addition to the shade and blind systems widely used in Europe, researchers in the U.S. and Australia are developing new electrochromic windows whose optical properties can be dynamically controlled from clear to dark. We describe field test results from two dynamic façade solutions in the U.S. We tested electrochromic “smart glass” prototypes in three side-by-side full size test rooms in Berkeley, CA with integrated HVAC and lighting systems. Energy and demand impacts of alternate control strategies were measured and occupant response studied. More conventional automated, motorized blinds and shades provide solutions today in many buildings. Working with the New York Times in the design of their new office building in New York City, a full-scale mockup of part of a typical floor of a 52 story, all-glass building was built, and a variety of interior motorized roller shades and dimmable lighting was extensively tested, simulated and optimized. Performance specifications were developed to guide competitive procurement, The control and integration results from both tests reinforce both the advantages and the challenges of smart, automated controls, and demonstrate that dynamic facade technologies can provide desired daylighting performance levels and overall energy benefits, as well as occupant satisfaction and environmental conditions conducive to a productive work environment.

Dynamic Daylighting Solutions for Façade Systems: Automating Interior Shade and Blind Systems

Shades and blinds are used in most U.S. buildings today but unlike European experience virtually none are motorized and few are externally mounted. Automated shading systems account for only 2-

3% of shading system sales and the systems available do not have the control responsiveness needed to guarantee good performance. The assumption is that that these shading systems are available for occupants to control to meet comfort needs but they are not relied on to control building performance. One outcome is that most energy standards do not provide any code compliance credits for systems that rely on occupant action since the response is unknown and uncertain. Furthermore engineers will generally size HVAC systems assuming worst case operating procedures – e.g. in this case that the systems are not deployed.

Integrating Motorized Roller Shade Systems and Daylighting Controls: New York Times Mockup

In the mid 1990s we developed an automated venetian blind system with smart controls that worked well in field tests to reduce lighting and total energy, and peak demand, and was rated well by occupants. Although the measured results looked good, no U.S. manufacturer followed up with products. Roller shade systems are also commonly available with many different fabrics encompassing a wide range of solar optical properties. Roller shade systems are mechanically simpler, but they have more limited optical control than horizontal venetian blinds, since once the shade fabric is selected the control is based largely on their position between up and down. For buildings with large, highly glazed facades roller shades and venetian blinds are the primary options available today for sunlight and glare control.

Over the last three years we have been helping test, specify, procure and commission a high performance daylighting system that employs an automated, motorized roller shade system in conjunction with a high transmittance, all glass façade and dimmable photocell controlled lighting for the New York Times headquarters building under construction in New York City. The 52-story 140,000 m^2 building will utilize fixed exterior shading and fritted glass in some locations but will require shades for sun control and glare control and for thermal and visual comfort as well as energy management.

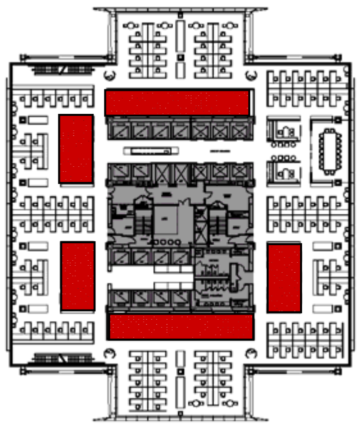


Figure 3: Exterior View of NY Times Mockup and Typical floor plate

Left: Photograph of mockup exterior showing external shading and roller blinds deployed behind the glass; Right: cruciform floor plan showing enclosed offices located toward the core.

The exterior of the building utilizes a highly transparent (Tv=0.75) floor-to-ceiling, all-glass façade that encouraged openness and communication with the external world, consistent with the owner's philosophy of a "transparent organization" and their dedication to creating a high quality work environment for their employees. Low 1.22-m high partitions were used to reinforce the sense of openness and to let the daylight penetrate deeper into the space. A cruciform floor plan and a generous ceiling height further enhance daylight availability in the spaces. Overall solar heat gain is a concern in any highly glazed façade. In this design, it is controlled with spectrally selective glazing

(SHGC = 0.39, U-factor = 1.53 W/m^2-°K) and with an array of exterior fixed ceramic rods designed to block and diffuse sunlight. (Fig. 3) Even with these systems the owner understood that the transparency of the façade would generate potential glare and visibility problems for employees using computer screens.

A partnership was created between The New York Times, its design team and LBNL to address this problem of a fully automated daylight control and shading system that would save energy and manage an indoor luminous environment conducive to employee comfort and productivity. A full-scale 401 m^2 daylighting mockup was constructed near the building site and two sets of vendors were invited to install their shading and daylighting equipment. The mockup was monitored by LBNL in partnership with the vendors over a nine-month solstice-to-equinox field test with support from the New York State Energy and Research and Development Authority (NYSERDA).

Initial Performance Results from The New York Times Daylighting Mockup

The daylighting mockup test program was designed to: 1) enable vendors to demonstrate features of their systems, 2) fine tune their systems to meet the evolving requirements of the building owner, and 3) understand the benefits and limitations of each manufacturer's approach to shade management and daylighting controls. The mockup would allow them to visually assess the quality of light in the space and provided a testbed to explore the issues of glare control and shade management. A further objective of the public agencies supporting the research was to help broaden the market interest in these systems and design approaches with visits to the mockup from other design firms and owners.

The full scale mockup consisted of the southwest corner of a typical floor and was fully furnished. The objective of the test of multiple systems was not to perform a side-by-side comparison of the two "competing" systems but rather to understand how vendor decisions regarding control infrastructure and design might impact actual field operation. The end goal of the monitoring phase was the development of a performance specification that was open for bid by any vendor. The performance specs can be downloaded from the project website in the reference section.

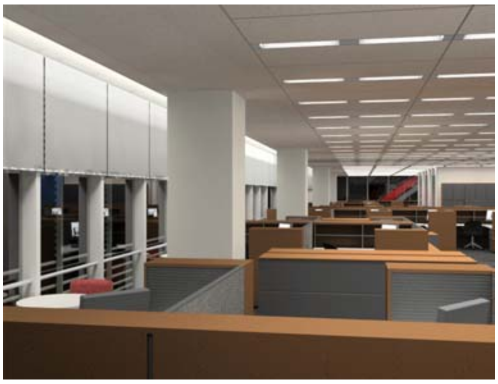



Figure 4: NY Times Mockup interior photo (l) and Radiance rendering (r)

Photograph of mockup interior (left) and RADIANCE nighttime rendering of the same space (right). RADIANCE simulations were used to explore shading and lighting issues.

Daylight work plane illuminance and distribution, electric lighting energy use, various parameters related to visual comfort, control operations, exterior solar conditions, and other environmental parameters were monitored continuously (1x/min, 24/7) to capture the full range of solar conditions. Manufacturers altered their systems in response to interim performance data from LBNL when it was demonstrated that the owner's specifications were not being met.

Detailed technical results of the daylighting study are available in reports on the LBNL website (see reference section in this paper). Initial results demonstrated that the window and automated shade system provided useful daylight throughout the 13.4 m deep perimeter zone, enabling significant dimming of the electric lighting throughout much of the zone. For this building design with its all-glass façade and minimal interior obstructions, even on the northwest side the daily lighting energy savings were 20-40% at 3.4 m from the west-facing window. The shading systems were controlled to provide a bright interior environment and control window glare. Lighting energy savings were substantially greater in zones daylit bilaterally from the south and west facades, averaging 50-80% at 3 m from the façade and still achieving an average of 40% savings at 6 m depth.

Daylighting savings were achieved with an automated shading control strategy that consistently blocked direct sunlight as well as adverse sky glare. When deployed the shades also reduced interior daylight levels, lighting energy savings, and access to view. The roller shade systems under consideration had an openness factor of 3% with an associated visible transmittance of about 6%. Other fabrics are under consideration for different facades and floor levels.

While daylight levels can be calculated with some reliability, glare is not easily simulated in a meaningful way. The mockup provided useful testing capabilities to assess glare, allowed extensive exploration of alternate control strategies under a range of sun and sky conditions. In the final building, while the shading systems will be fully automated luminous conditions will first be tuned to the specific requirements of the occupants and work groups, and then dynamically adjusted based on window orientation, and degree of obstruction and/or daylight reflection from the urban surroundings. In order to estimate these impacts the mockup results were supplemented by extensive simulation studies using Radiance. These studies explored the performance of prototypical workstations on different orientations and different floors in order to account for the urban context of this building. Adjacent buildings shade the lower floors to varying degrees and building orientations that normally do not experience direct glare from sunlight e.g. North, may be subjected to reflected sunlight from adjacent buildings with reflective glass. These effects were observed and assessed using an extensive set of Radiance simulations for conditions at the Times building site. Based on this work the final specification for the operation of the shade control systems was a luminance-based control system that dynamically can respond to the wide variation of conditions at each shade location that one might find in an urban environment.

Since occupant response to the new workspaces was important to the owner over 200 Times employees had a chance to spend time in the mockup. Although it was not possible to conduct controlled occupant studies the future occupants did provide valuable feedback to the designers. The employees clearly preferred the brighter daylit space compared to the darker, less daylighted spaces in buildings that most currently occupy. They found the quality of daylight to be palpably different in the morning versus the afternoon and were delighted with the subtle shifts in color, intensity, sparkle, and mood throughout the day.

Based on the specifications developed in this field test and simulation phase, and other extensive owner studies intended to simplify system design and minimize costs, a competitive bid process was initiated in 2004 for the daylight dimming controls and the automated roller shade systems. Multiple vendors responded with bids that met the performance specs and contracts were ultimately signed with vendors for these systems. This procurement represents the largest daylight dimming systems and automated shading systems in North America at this time and sent a signal to other owners and system vendors that such systems are viable options in today's marketplace. In the final phase of the project, commissioning carts are being developed to test compliance with the performance specification for each work area in the building. Construction of the building is underway, with initial system installation in late 2006 and occupancy is expected in 2007. It is hoped that field studies in the completed building will allow the design and modeling results to be checked against reality is what is achieved in the building. The control systems for lighting and shading have the capability of being fine tuned to accommodate differences in site conditions and user needs.

Smart Glazing Systems: Field testing electrochromic glass for daylight and solar control

Owners worry about the maintenance of motorized shades and blinds, and ask why dynamic control of transmittance cannot be directly incorporated into glazing layers. Researchers have been developing switchable "smart glazings" for over 20 years and the laboratory accomplishments are now beginning to become available for field-testing in larger prototype form. But even if the glazing products switch as desired, building operating strategies must be developed not only for energy and load control but to meet occupant needs in terms of comfort and productivity. As with the shade and blind studies above, field studies in test rooms and mockups are an important adjunct to the extensive computer modeling studies that have already been completed to quantify potential energy savings.

In 1999 we retrofitted several rooms on an Oakland test building with a first generation electrochromic window. The optical system changed from a clear state with a transmittance of 51% to a dark state transmission of 11%. The system switched smoothly although full switching could take in excess of 15 minutes, the dynamic range was not adequate to control glare and the coatings had a noticeable blue tint in the switched mode. The test rooms allowed the lighting impacts to be measured but it was more difficult to assess cooling impacts.

In 2002 we constructed a new test facility at LBNL with three side-by-side test rooms with unobstructed south views. The entire façade of each room can be replaced. The lighting power and the heating and cooling in each room is individually monitored and the rooms have a full array of illuminance and luminance sensors for monitoring. The rooms were fitted with new electrochromic glass samples over the complete façade as shown in figure 5. Since the prototypes were of limited size the current façade requires 15 glazing panels. The visible transmittance of these prototypes can be varied over a range of from 60% to 4%.

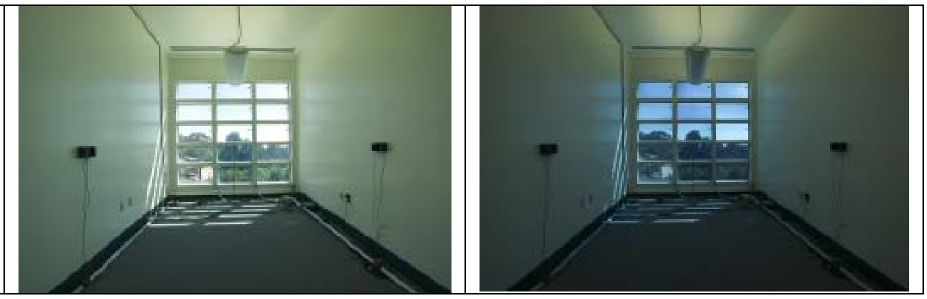


Figure 5: Interior view of Electrochromic façade in two switched states
Two views of a test room in the LBNL façade test facility, showing the darkening sequence. The transmittance of these prototypes can be switched from 60% to 4%. (left to right: 1) Sunny condition, switching starts, T=60%; 3) Sunny condition, switching complete, T=4%). In later studies office furniture was added to the rooms for occupant studies.

Over two years of extensive field tests have been completed exploring the energy savings achieved with different control strategies. A glazing whose properties can be dynamically controlled from TV: 60%-> 4% can be used at any instant to minimize cooling or maximize daylighting benefit. The optimization challenge comes when one wishes to minimize glare for occupants as well as optimizing energy use. For example when direct sun is present, glare control for occupant comfort and task visibility will dictate that the glazings be darkened to their lowest transmission state. In these circumstances the daylight levels in the space are low enough that electric lighting is needed to reach the nominal task illuminance setpoints. In a control space with a venetian blind that blocks direct sun, the daylight savings will be captured. Over a long time period with different sun and sky conditions the following picture emerges from the measured performance data for different control strategies. The electrochromic test room almost always has equal or lower cooling loads. Compared to a reference room with fixed venetian blinds and no electric lighting controls (the typical case today) the electrochromic façade saves 30-60% of the lighting energy. But compared to the same reference room with daylight dimming controls the electrochromic performance relative to the reference can vary over a wide range of 50% savings (Fig 6 "1-zone daylight control" case) to 20% increased energy use (fig 6, "1-zone glare control" case - Note that in this case the reference room with blinds may have glare levels that are worse than the test room.) The increased lighting energy use in the test room occurs due to the conditions noted above, when the electrochromic switches to its lowest transmission mode to control glare. These results led us to change the operation of the façade so that the transmittance of an upper and lower glazing can be independently controlled. In these tests the upper 6 glazing units were controlled to provide adequate daylight admittance to brighten the room, while the lower 9 glazing units were modulated to control glare. In this operational design the test room often demonstrated large savings but its lighting performance was never worse that the reference case (fig 6, 2 zone daylight and glare case). The approach to modulating the transmittance of different glazings to maximize daylight levels but minimize glare is now being further explored using Radiance modeling and optimization techniques. New control algorithms will be implemented in the facility and tested over the next year.

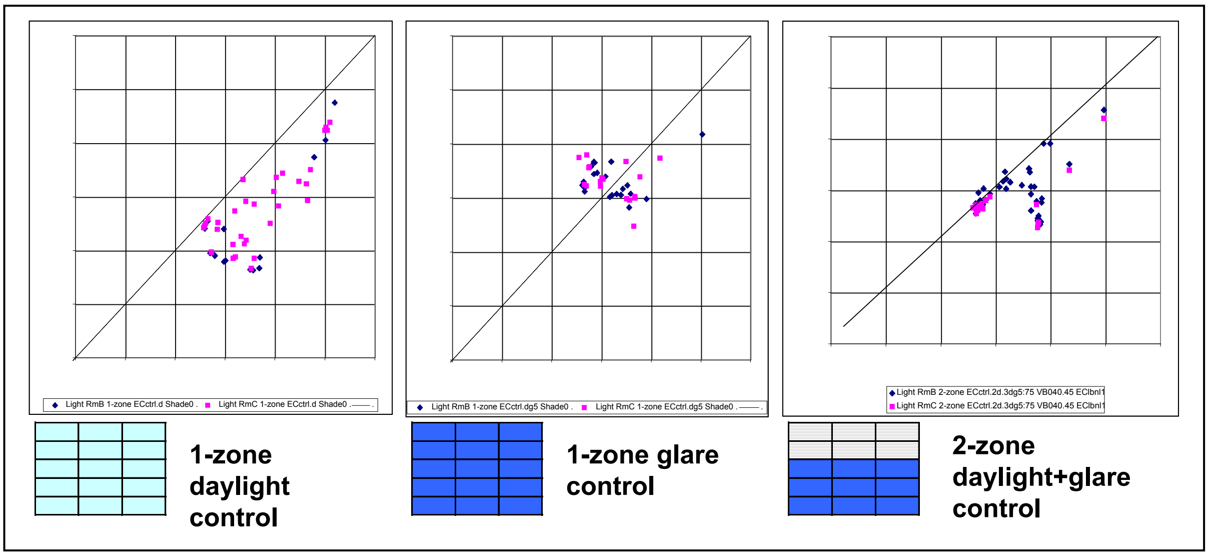


Figure 6: Lighting Energy Use- Reference vs Test Room for Alternate Control Strategies

Daily Lighting energy use in electrochromics test room (vertical axis) vs reference room with blinds (horiz. axis) for three control schemes. Points on the diagonal line indicate the reference and test room have equal energy use; points in the upper left indicate the electrochromic uses more lighting energy; points in the lower right indicate the electrochromic saves energy compared to the test room.

We have conducted human factors studies in this facility to determine the operating and control parameters of the glazing and lighting systems that provide visual comfort and enhance visual performance. Early results suggest that the lowest transmittance level of the current glazing prototypes, 3-4%, is usually adequate for most glare control situations although some users chose to deploy blinds even with the electrochromic at its lowest transmittance level so that lower levels would be useful at times with direct sun. Better tools are needed to quantify the visual environment in conjunction with subjective and objective user studies in these spaces. Working with collaborators in the IEA 31 Daylighting task we have developed new glare assessment approaches by processing of high dynamic range image data from electronic cameras to quantify, display and understand these complex environmental parameters that directly impact occupant comfort, satisfaction and performance (fig. 7).

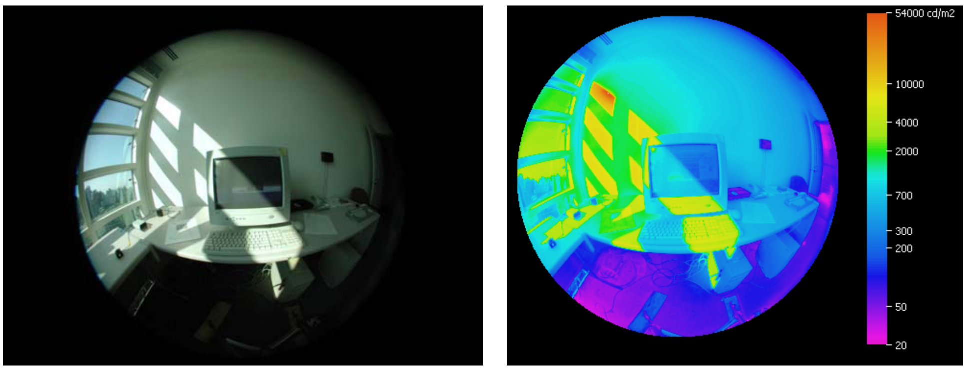


Figure 7: Luminance data collection using HDR photography with Occupant studies

Figures 7.1 and 7.2 CCD photo of workstation (left) and false color luminance map (right) produced from image at left and 5 additional photos. Luminance map provides a dynamic range of 5000:1

Conclusions

A renewed and growing interest in daylighting and sustainable design has led towards greater use of highly glazed building facades. Balancing the need for view, glare control, thermal comfort with solar load control and daylighting energy savings is a complex challenge. In order for these designs to meet often contradictory performance objectives they will need to have a degree of active, reliable management of solar/optical properties of the building envelope that has rarely been consistently and economically achieved in buildings. Some of the technologies to provide active control of fenestration transmittance and associated control of electric lighting in building interiors are now available and have been shown to be capable of good performance and others will emerge. However it will take better and cheaper hardware, additional exploration of systems integration solutions, new sensors and controls, improved commissioning, a better understanding of occupant needs and preferences, and better real time, adaptive controls to fully realize the potentials of these emerging technologies.

References

Materials describing portions of this work related to the New York Times project can be found at http://windows.lbl.gov/comm_perf/newyorktimes.htm

A complete list of references and current R&D papers on facades project and tools at LBNL can be downloaded at: http://windows.lbl.gov

Reports from the completed work of the IEA SH&C Task 31 can be accessed via the IEA website, http://www.iea-shc.org/task31/index.html

Acknowledgements

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Lighting in Call Centres

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Exergy Australia Pty Ltd

Abstract
A lighting satisfaction study has been undertaken in six Australian public sector call centres. The study was initiated by the dual motives of saving energy and improving levels of occupant satisfaction. A combination of technical measurements and occupant questionnaires was used to establish the technical parameters of the lighting installation and the user responses. The technical parameters were then cross correlated against user satisfaction levels to identify what factors appeared to be associated with higher levels of satisfaction or dissatisfaction.

The assessment demonstrated relatively clear relationship between a number of key design parameters and user satisfaction. Key parameters were found to be the management of fitting luminance over the full range of viewing angles and the achievement of an illuminance on the working plane of 200-250 lux. Interestingly, it has been found that traditional louvered low glare fittings are a poor solution, as these appear to have inadequate control of glare at around 30-60º viewing angle. Similarly, the use of fittings with more than one lamp has been found to be largely incompatible with achieving the desired levels of performance.

Trials of fittings that are compliant with recommendations of the study have shown a high level of user satisfaction, using a relatively cheap, low-tech fitting. Furthermore, given the reduced lighting levels and fitting types, an energy efficient installation of around 5W/m² can be achieved using T8 lamp technology.

Introduction
Centrelink is an Australian Government agency that co-ordinates and delivers a range of social security and human services. Centrelink's call centres are open plan offices that house 150 – 250 staff processing mainly inbound calls. Centrelink is currently implementing a portfolio-wide energy efficiency programme. As an extension of this programme, and in response to concerns about the level of complaints, Exergy were engaged to investigate lighting and visual comfort at six sites.

Lighting at Centrelink call centres and other offices in Australia is generally designed with reference to Australian Standard 1680.1.1990 (recently updated). For areas where screen-based tasks are undertaken, the Australian Standard recommends a minimum maintained illuminance of 240 lux, horizontal illuminance uniformity (minimum/average) of 0.7, and maximum glare index of 19. Our experience with both the users and designers of office lighting systems in Australia suggests that visual comfort considerations are poorly understood, with concerns mainly limited to minimizing onscreen glare from fittings.

Methodology
A broad frame of enquiry was developed to cover various parameters relating to the indoor environment and workplace culture. This broad approach facilitates the investigation of possible interactions between lighting complaints and other aspects of the site operation. Site investigations covered the following issues:

- Luminaire and lamp type, condition and mounting arrangement, orientation relative to workstations, and luminance profile.
- Availability and nature of natural lighting, including considerations of window size and location, glazing treatments, internal and external shading.
- Horizontal, vertical and on screen illumination levels at the workstations, as well as on-ceiling illuminance.

- Monitor type, size and display colour.
- Furniture and décor colour, type and surface finish.
- Special features or facilities in the fit out.
- Indoor air quality issues including HVAC system type and condition, ventilation arrangements, and staff satisfaction with the air conditioning.
- Visual tasks undertaken at the site.
- The level and nature of lighting complaints, and the management and OH&S practices with respect to lighting complaints.

A series of physical measurements and face-to-face interviews was conducted to characterise each site against the environmental and cultural parameters.

Interview subjects included site managers, Occupational Health and Safety co-ordinators, Team Leaders and a small number Customer Service Officers (CSOs). CSO interviewees were selected pragmatically on the basis of their availability, although we attempted to select interviewees from a range of physical locations and work group teams. The samples of CSOs were too small to be considered statistically significant, instead it provided anecdotal or case study evidence. Managers, Team Leader and OH&S interviews were a key source of information on the extent of problems across the site. The interviews used predominantly open ended questions, concentrating on interviewee-nominated concerns. A comprehensive workstation assessment was also completed at the desk of each CSO interviewed. Horizontal, vertical and onscreen illuminance measurements were also repeated at 20 to 30 other workstations around each site.

Based on the results of the interviews, each site was awarded an “A”, “B” or “C” grading in each of the following performance categories:

- Too bright
- Too dim
- Peripheral glare (attributed to light fittings)
- On-screen glare
- Upwards glare (reflected from keyboard or desk surface)
- Window-related issues.

An “A” was awarded to sites where no problems were identified in a particular category in any interviews. A “B” was awarded where problems existed but were being managed effectively, with irritation and discomfort apparently mild and/or limited to isolated cases. A “C” was awarded where problems appeared to be causing more widespread irritation or more severe symptoms.

The data was analyzed to investigate the existence and strength of relationships between site performance in each category and average illuminance, uniformity and typical luminance profiles. Individual interviewee responses were assessed against workstation illumination characteristics on a similar basis.

Table 1: Basic site characteristics

	Adelaide	**Brisbane**	**Cairns**	**Gosford**	**Liverpool**	**Newcastle**
Age of site (years)	>4	1	2	1	5	2
Desks	Beech.	Beech	Beech	Beech	Light grey	Beech.
Wall colour	Light, dark feature walls.	Light, medium feature walls.	Light. Medium feature walls.	Light. Dark feature walls.	Light. Dark feature walls.	Light. Varied feature walls.
Partition colour	Medium blue.	Dark blue and burgundy.	Mostly red.	Dark blue and burgundy.	Dark blue and green.	Dark blue.
Carpet colour	Light brown.	Dark blue.	Dark blue.	Dark blue.	Dark blue.	Dark blue.
Ceiling colour	Light.	Light.	Light.	Light.	Light.	Light.
Window height.	Floor to ceiling	70%. Low window-wall ratio.	70%	70%.	70%	70%
External shading	Overshadowing by neighbouring buildings.	Limited.	Dense plantings.	Horizontal overhangs. Solar penetration at some angles.	-	Horizontal overhangs. Windows are tinted.
Internal shading	Venetians, 60% closed.	Venetians, all closed; roller glare blinds down.	Venetians. Mostly partly open.	Venetians. Mostly partly open.	Venetians, mostly closed.	Venetians. Mostly partly open.
Air conditioning type	Variable Air Volume (VAV)		Variable Air Volume Direct Expansion units.	DX units with Volume Control Dampers.	Constant volume DX units	Variable volume DX units with economy cycle and user adjustable setpoint temp.
AC diffuser condition.	Good.	Good.	Good.	Good.	Good.	Good.
AC Issues?				Ongoing maintenance problems with some units.	Pigeon droppings around fresh air intake during first visit, subsequently removed.	
Special features	Feature walls on first floor only.	Paintings, feature walls for visual interest.	Beer fridge, barbeque area, Paintings,	Tea room with some natural lighting.	Tea and lounge rooms at the perimeter of the	Gym, pool table, staffed-kiosk, fish tanks.

	Adelaide	**Brisbane**	**Cairns**	**Gosford**	**Liverpool**	**Newcastle**
			columns for visual interest.		site with good natural light availability.	
Ceiling height (m)	3	3	3	3	2.7	2.95
Dominant lamp type	33 (mono), 36W	Triphosphor, 28W	840, 36W	840, 36W	Before upgrade: 830, 840, 36W. After upgrade: Colour 840 36 W lamps throughout.	Monophosphor, 36W.
Lamps per fitting	2	1	1	1	Initially 2. Only 1 after upgrade.	1
Ballast type	Magnetic	Electronic	Fixed electronic.	Magnetic.	Fixed electronic.	Magnetic.
Lateral grid spacing	1.8	2.1	2.4	2.1	3.3	3
Fitting length (mm)	1200	1200	1200	1200	1200	1200
Fitting width (mm)	300	125 (300mm incl. air boots.)	300	300	300	300
Diffuser type	Prismatic	Specular metal louvre 1*23 cell.	Semi-specular metal louvre 1*10 cell	Semi-specular metal louvre 1*10 cell	Initially semi-specular metal louvre 1*10 cell. Subsequently, silver-tint prismatic K19.	Semi-specular metal louvre 1*10 cell
Secondary fitting illuminating open plan areas	Nothing significant.	Undiffused compact fluorescent down lights causing problems.	Nothing significant.	Spill from glass partitioned meeting rooms.	Nothing significant.	Halogens at perimeter. No problems reported.
Dominant Monitor	Dell, 40 cm diagonal, CRT, curved screen.					
Monitor glare screens in use?	Approx. 12	Occasionally.	No.	Rare.	Occasionally.	Rare.
Keyboard (predominant)	White text on black background.	White text on black background.	White text on black background.	White text on black background.	White text on black background.	White text on black background.

Results

Site Characteristics and Performance Ratings

Basic characteristics of the environment at each site are summarised in Table 1. The table includes a description of the changes to the light fittings at Liverpool. The new single lamp fittings included at Liverpool included a specular reflector to maximise light output from the fitting.

Glare index data was only available for two sites (Brisbane and Cairns). Both were found to comply with AS1680 maximum glare index requirements.

At all sites, most occupants had access to items of visual interest, such as brightly painted columns, strong coloured feature walls, paintings, external views or decorations in the middle distance.

Management and Operational Practices

The sites share a number of operating and management practices.

- Predominantly computer based work. CSOs spend over 70% of their workday in front of the computer.
- The use of corded headsets by CSOs, limiting their mobility while talking on the phone.
- Extensive and fine-grained time logging requirements for CSOs.
- Highly mobile team structures. Most CSOs had been at their current desks for less than 2 months.
- Similar mechanisms for reporting of lighting complaints. The Team leader is the first point of contact. If a problem could not be resolved within the team, it would be passed to an administration officer or staff-elected OH&S representative, and ultimately to the site manager and OH&S Co-ordinator. There was no dedicated reporting process for lighting complaints.
- Limited control by staff over their physical environment. Temperature and airflow settings were not readily adjustable. Light output from the fittings was fixed. Window blinds at most sites were left in a fixed position to avoid disturbing staff. Aspects of the environment controlled by staff include desk and chair and screen configuration, on-screen colour schemes, and office decorations.

Overall Visual Comfort Ratings

Overall visual comfort ratings awarded based on the interview results are summarized in Table 2. Results for Liverpool show performance both before and after the upgrade.

Table 2: Overall site rating summary. Legend: A = good, B=moderate, C=poor.

Category	Adelaide	Brisbane	Cairns	Gosford	Liverpool before upgrade	Liverpool 2006 (after upgrade)	Newcastle
Too bright	B	B	A	C	C	B	A
Too dim	B	A	A	A	A	A	B
Monitor glare	C	B	A	C	B	B	B
Upwards Glare	A	C	B	C	C	B	A
Peripheral glare (fitting)	B	B	B	B	C	B	A
Window Issues	A	A	A	B	A	B	B

Relationships Between Visual Comfort and Site Illumination Characteristics

Desktop Illuminance Impacts on Glare and Brightness

The relationship between average desktop illuminance and upwards glare problems is illustrated in Figure 1. The relationship between average desktop illuminance and the "too bright" site score is shown in Figure 1: Average desktop illuminance and upwards glare score.

2. There is a reasonably strong relationship between horizontal illuminance and the presence of upwards glare, and the overall sense of the site being "too bright". These site wide trends can also be seen in the individual interviewee data, as illustrated in **Error! Reference source not found.**3, which also shows that very few interviewees were concerned about light levels being too low.

Overall, it can be identified from the figures that an average desk top illuminance of less than 250 lux is compatible with the least number of complaints.

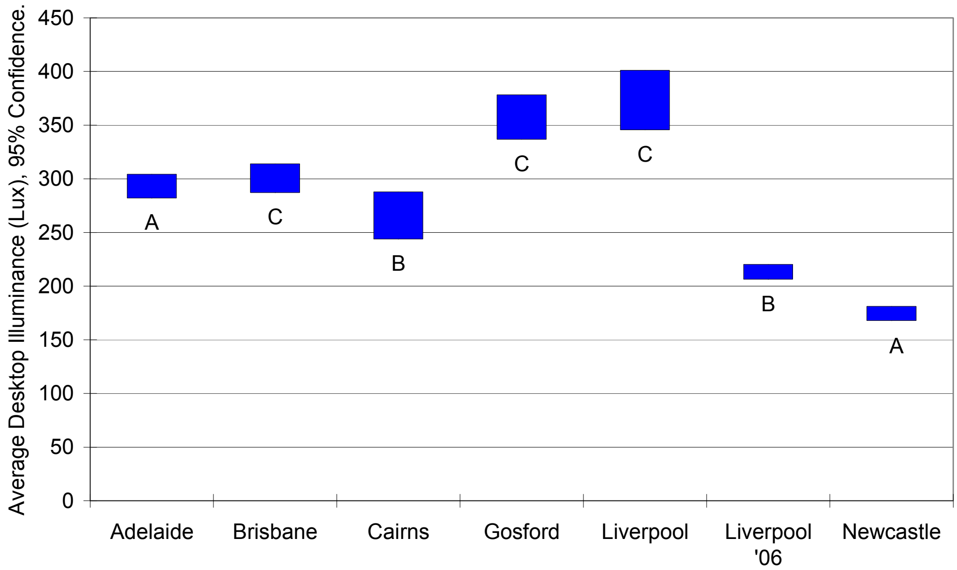

Figure 1: Average desktop illuminance and upwards glare score.

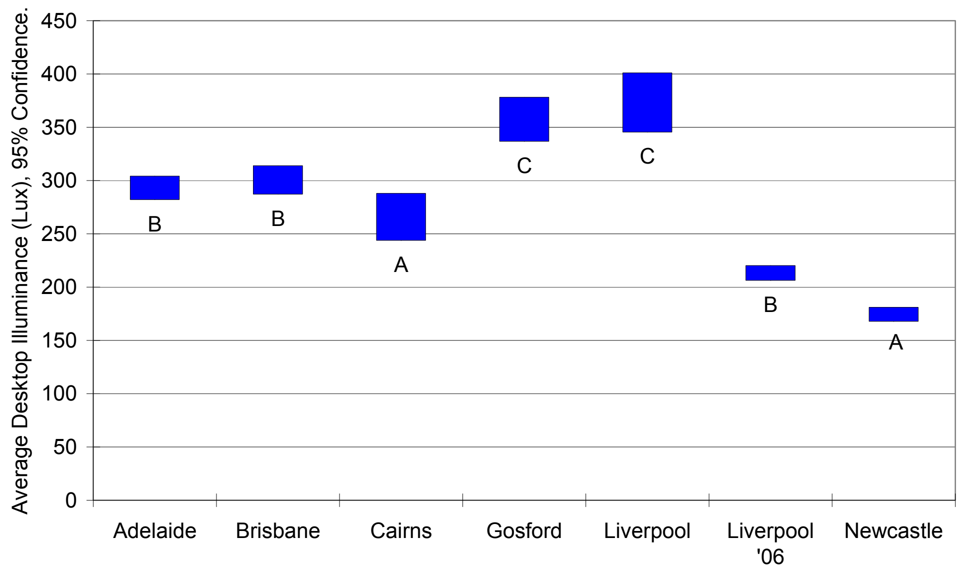

Figure 2: Average desktop illuminance and "too bright" performance score.

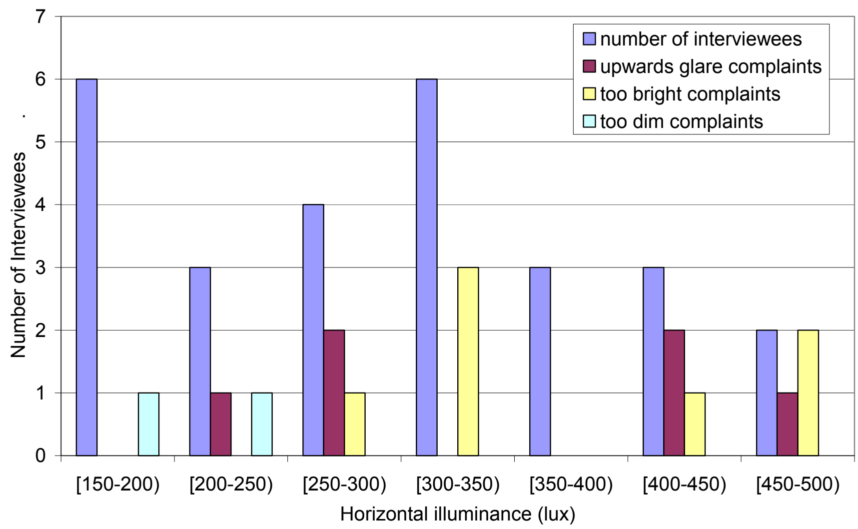

Figure 3: Relationship between average horizontal illuminance measured at the desk reported complaints of upwards glare or excessive brightness.

Onscreen Illuminance and Monitor Glare
On screen illuminance was assessed by placing a light meter with the sensor vertical and facing the computer user, immediately in front of the monitor screen, Average onscreen illuminance at each site is illustrated in Figure 4. The overall rating of each site with regard to the monitor glare performance is superimposed on the chart. While the two sites with the poorest monitor glare rating tend to show higher average onscreen illuminance, no clear relationship is apparent from this chart. In particular, it is notable that at Newcastle, where onscreen illuminance is clearly lower, there is still a moderate monitor glare problem.

At an individual interviewee level, a slightly stronger trend is visible, as illustrated in Figure 5. This indicates that maintaining vertical illuminance levels below 200 lux may reduce monitor glare complaints. However, it is also suspected that other factors such as screen luminance, contrast and specularity are also significant factors in determining the probability of monitor glare issues.

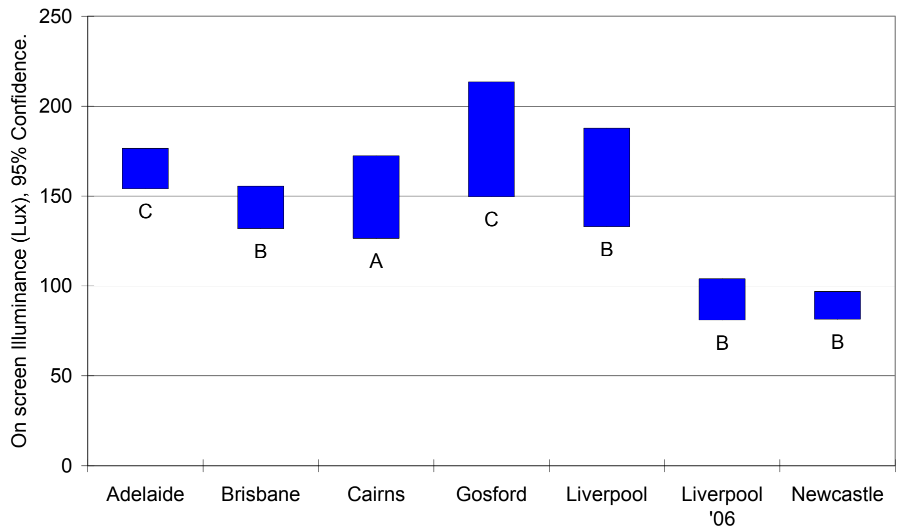

Figure 4: Relationship between average onscreen illuminance vs onscreen glare score

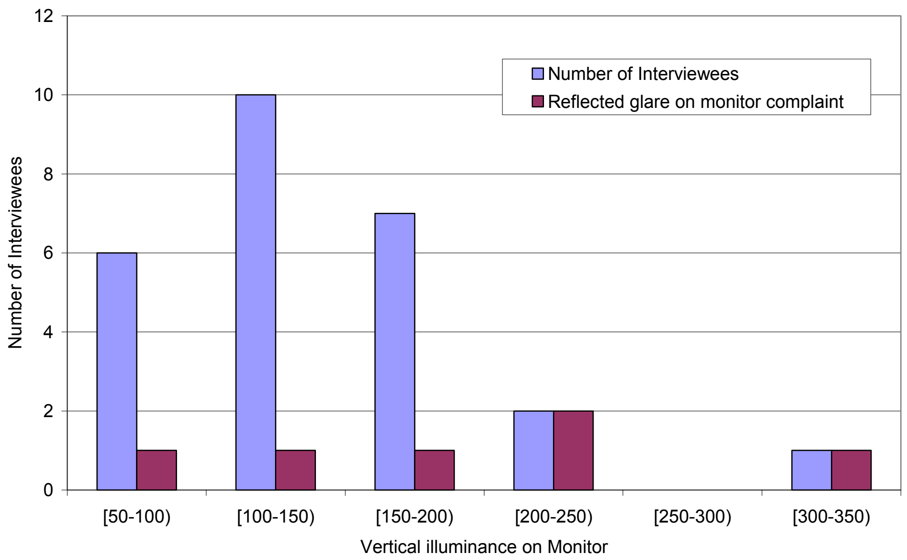

Figure 5: Measured onscreen vertical illuminance and reported monitor glare problems

Vertical Illuminance Impacts on and Peripheral Glare and Brightness

Vertical illuminance was measured for light coming towards the interviewee in the periphery of their vision when working at the computer. Peripheral glare performance is plotted against average vertical illuminance illustrated in Figure 6, while Figure 7 shows the relationship between average vertical illuminance and the sense of the site being “too bright”.

Figure 6 shows evidence of a possible relationship between vertical illuminance and peripheral glare The site assessed as having the worst peripheral glare problem (Liverpool prior to the lighting upgrade) has one of the highest vertical illuminance figures, while the site with the lowest peripheral glare problem (Newcastle) had the lowest vertical illuminance. A stronger relationship is apparent between vertical illuminance and the overall sense of brightness, with higher illuminance sites much more likely to be considered too bright.

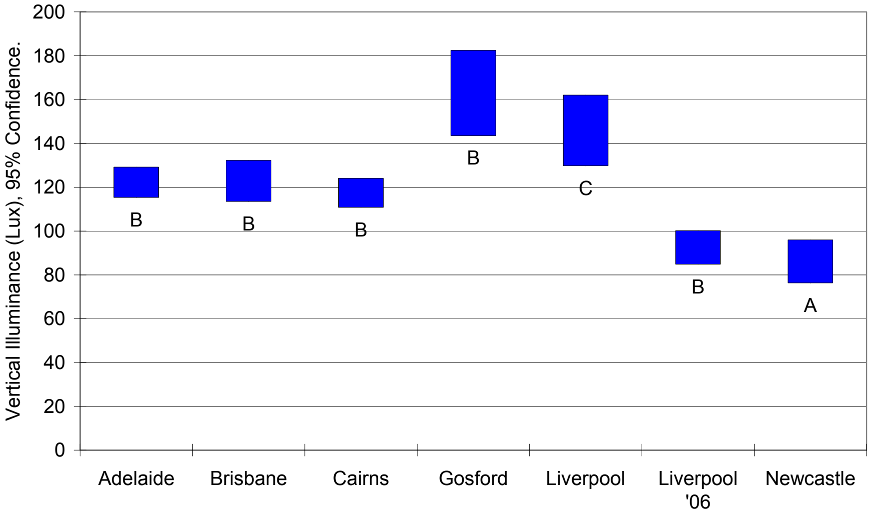

Figure 6: Relationship between average vertical illuminance (lux) and assessed peripheral glare score.

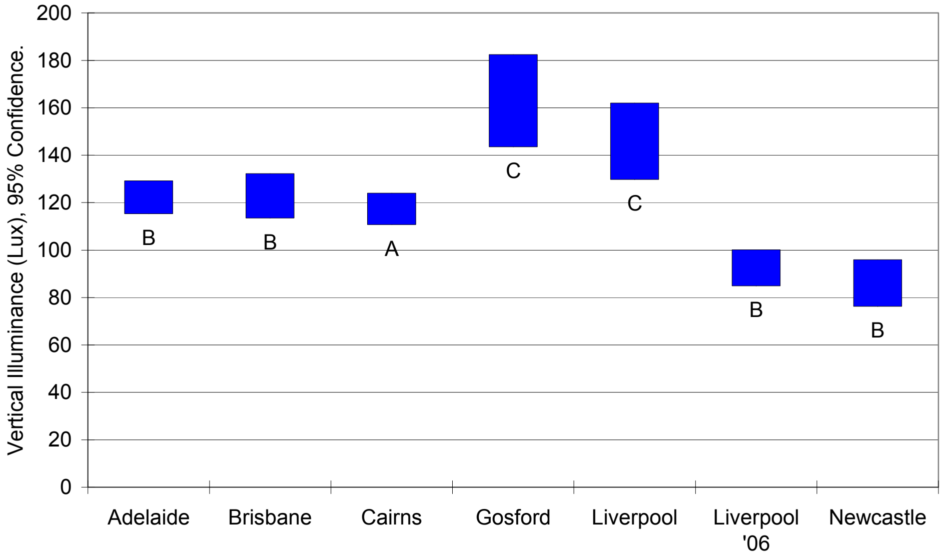

Figure 7: Relationship between average vertical illuminance (lux) and assessed "too bright" comfort rating.

The relationship between vertical illuminance and peripheral glare complaints is illustrated in Figure 8 and Figure 9. These results support findings from the site-wide illuminance analysis, with peripheral glare and brightness complaints appearing more probable for average vertical illuminance levels over 100 lux. Figure 9 suggests that individuals are much less likely to suffer from problems with peripheral glare when the uniformity is above 60%.

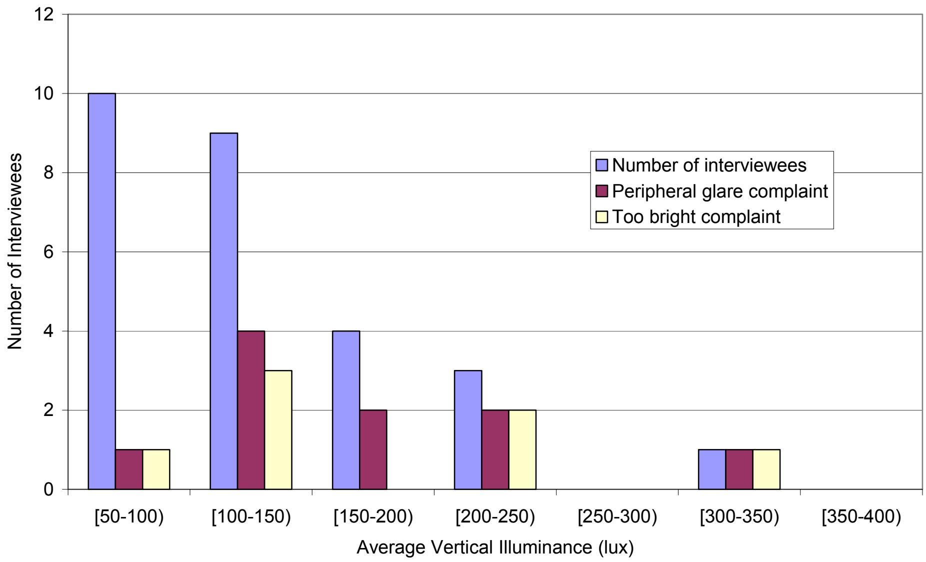

Figure 8: Relationship between the existence of peripheral glare and "too bright" complaints and average vertical illuminance.

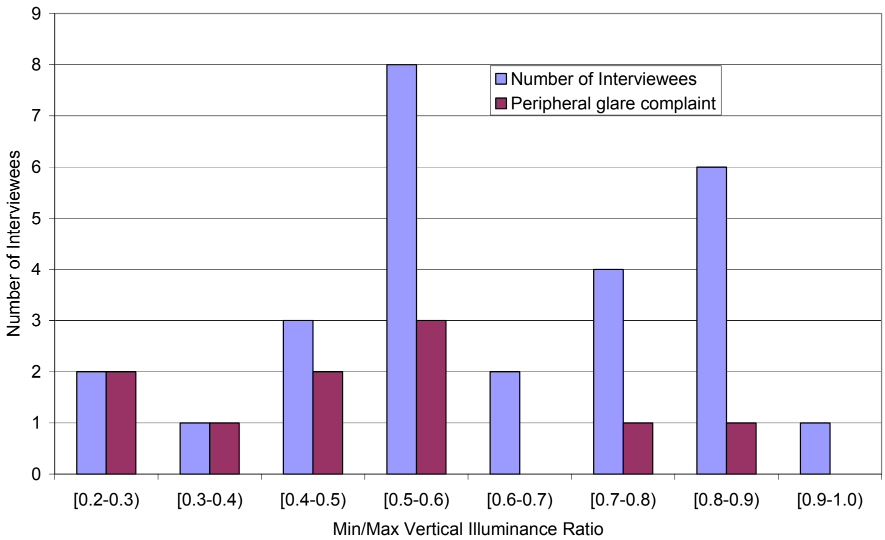

Figure 9: Relationship between the existence of a peripheral glare complaint and the ratio of minimum to maximum vertical illuminance.

Impact of Ceiling Illuminance

Ceiling illuminance and colour are key factors in determining ceiling luminance. However, all sites had white ceilings and average ceiling illuminance fell within a relatively narrow range of 30 to 60 lux. With so little to distinguish between the sites, the relationship between ceiling illuminance and occupant comfort was not investigated further.

Fitting Luminance Analysis
Luminance data was available for the light fittings at all sites except Gosford. The data are presented in Figure 10. The C-angles plotted represent typical viewing angles for the closest fittings to the occupants.

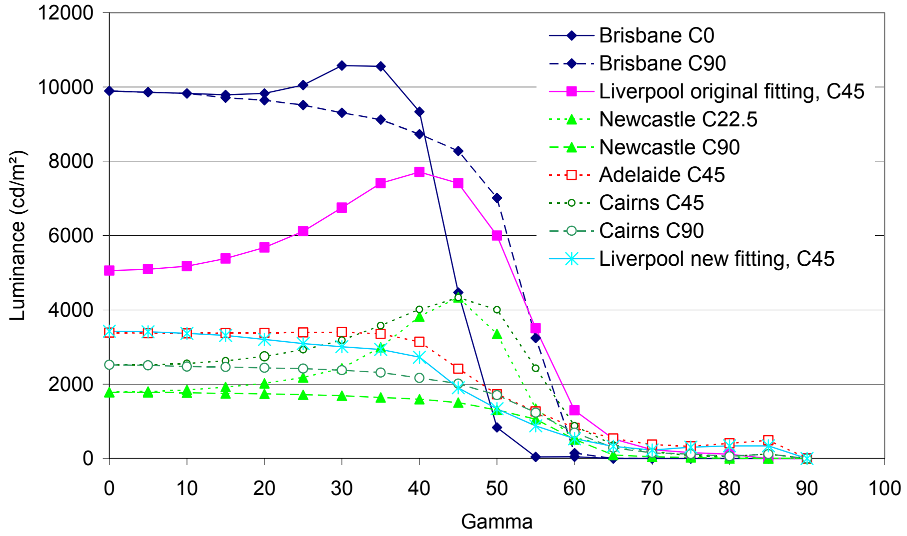

Figure 10. Luminance curves for fittings. The c-angles shown represent typical the range limits of viewing (C) angles for the closest fitting to each occupant.

Luminance Impacts on Upward Glare

The relationship between luminance in the 0-30° region and the assessed degree of upward glare problem across each site is shown in Figure 11. The 0 – 30°C region is considered critical because of the potential for specular reflections of desk surface items towards the viewers eyes. It can be clearly seen from the figure that a high luminance is correlated with a lower level of occupant satisfaction.

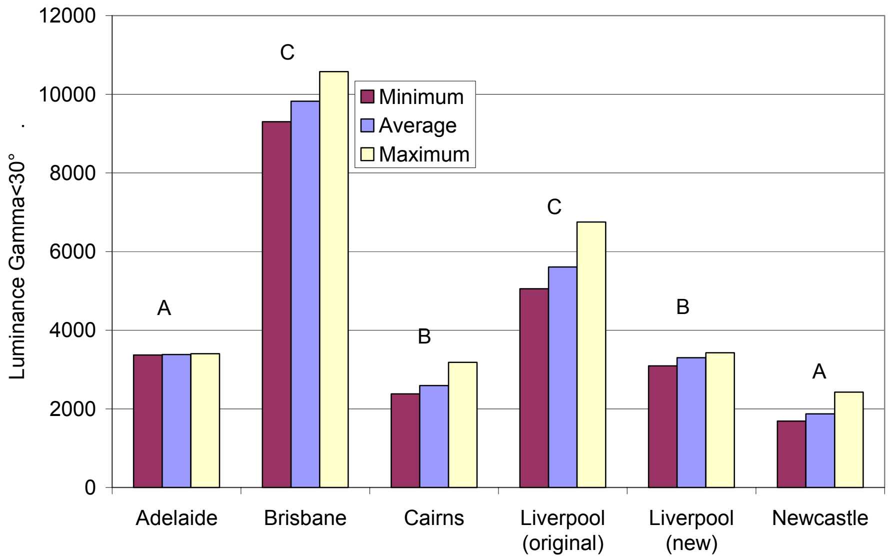

Figure 21. Relationship between low gamma angle luminance and perceived upwards glare discomfort. Upward glare ratings for each site are superimposed on the graph.

Luminance Impacts on Peripheral Glare

The relationship between luminance in the gamma =30-70° region and the assessed peripheral glare discomfort is shown in Figure 32. Note that at some sites only a portion of this gamma range has been considered as viewing angles are dictated by a fixed relationship between desk locations and the lighting grid. In the gamma = 30 – 70° range, high luminance fittings tend to appear as bright objects on the periphery of the line of site.

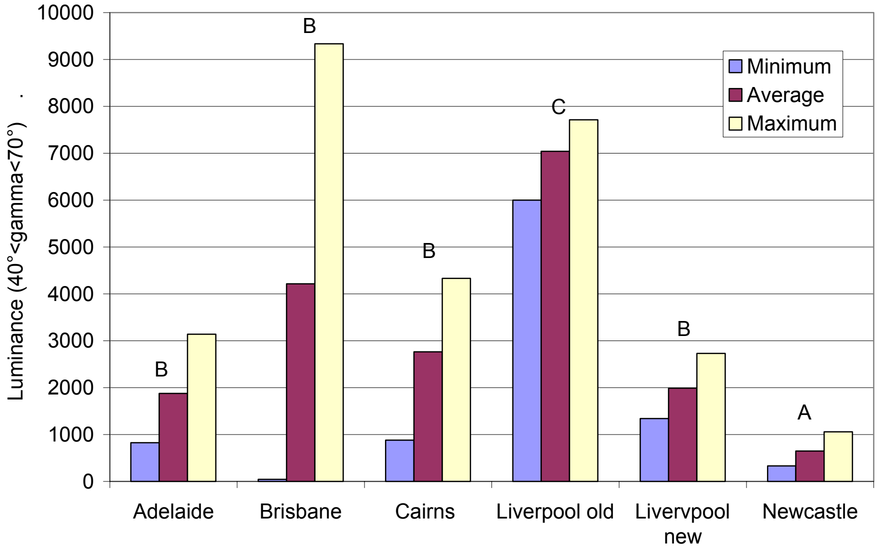

Figure 32. The relationship between fitting luminance in mid-range gamma angles and the peripheral glare discomfort score.

There is some evidence of a relationship between the peripheral glare discomfort and mid-angle luminance. Brisbane stands out as an exception to this trend, possibly because the sharp luminance cut off means that minor alterations in the relationship between the viewer and the fitting could create a substantial reduction in glare.

High angle Illuminance and On-screen Glare

The impact of fitting luminance on the assessed level of discomfort arising from on-screen glare is shown in Figure 43. It can be seen that there is not an obvious connection. This partly reflects the fact that on-screen reflections were in generally a relatively minor issue at all sites. However, it is notable that Adelaide and Liverpool, which were generally considered to be the poorest sites in this respect, have the highest average luminance.

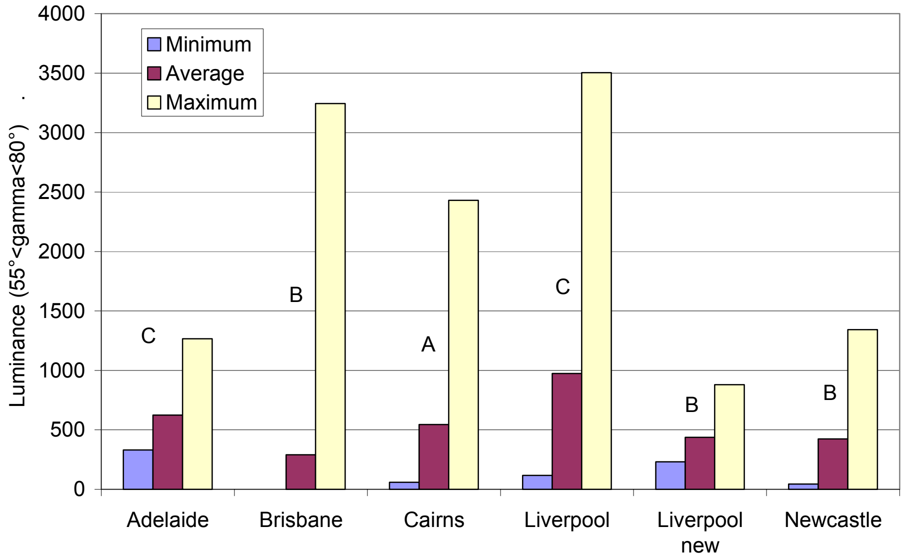

Figure 43: High angle glare and onscreen reflections.

Recommendations

Based on the preceding analysis, we have made the following recommendations to assist in reducing lighting complaints:

- Horizontal illuminance should be limited to no more than around 250 lux. Many call centre staff will tolerate an illuminance of well under the minimum threshold of 240 lux defined in the Australian Standard. However, some task lighting or areas with higher background light levels may need to be made available for individuals who require more light.
- Average vertical illuminance should be limited to no more than 110 lux.
- Vertical illuminance uniformity around the periphery of the occupant's line of site should be maintained above 0.7
- Fittings should be selected with a luminance at gamma<30° and at all C angles such that the luminance is less than 3500 cd/m²
- The selection of light fittings and the positioning of desks should be coordinated to maintain the luminance of the nearest fitting in the line of sight (30°<gamma<70°) as low as possible, and certainly below 2000 cd/m².
- Fittings should have a luminance at a gamma of 70° (and greater) of less than 1000cd/m². However, it is noted that absolute cut-off above this angle, as this creates a gloomy effect within the space and worsens uniformity.

Implementation Results

The recommendations above were implemented at Liverpool Call Centre in August 2005, as this had been the most problematic site to date. In the upgrade, the existing two lamp 10 cell lourve fittings were replaced with single lamp fittings with specular reflectors and prismatic diffusers, on the same grid as previous. The new fitting was broadly compliant with the recommendations other than fitting luminance in the region of 30-45°, as can be seen in the Figures,

It can be seen from Table 2 that the site performance improved in the categories of brightness, upwards glare and peripheral glare. The degree of improvement in satisfaction level is possibly not fully captured by the scoring system (which only awards an "A" in presence of no complaints). In practice, there was a significant reduction in the level of complaints about the lighting system and importantly there were no complaints indicating severe or debilitating impacts, in contrast to the original lighting arrangement.

A further benefit of the lighting upgrade was that the lighting power density for the site was reduced by 50% to approximately 5 W/m^2, resulting in a 50% reduction in lighting energy consumption overall. Given the positive impacts on employee satisfaction, this is a significant achievement.

Productivity Analysis

Centrelink routinely monitors a range of productivity indicators for its call centres. A limited amount of productivity data was made available for the Liverpool Call Centre, covering the period from early 2004 until January 2006. The new light fittings were installed at Liverpool in August 2005. The data showed that:

- There was a trend towards reduced unplanned leave during 2005. It is unlikely that this trend can be attributed to the new lighting arrangements as it started prior to their installation and, furthermore, a number of other leave management initiatives were in place. However, the trend continued without disruption after the new fittings were installed.
- There was a trend towards increased accuracy during 2004 and 2005 that continued without disruption after the new light fittings were installed.
- There was no trend apparent in customer satisfaction or call handle times.

Quantitative data is therefore ambiguous as to whether a positive impact on productivity has been achieved, although there would be no support that any reduction has occurred. It is noted however that the call centre manager felt that productivity improvements had been achieved as a result of the lighting improvements, due to the reduction in down time associated with meetings to discuss lighting issues. However, none of the available quantitative measures assess this factor.

Conclusions

A study has been undertaken of user satisfaction at six call centres for an Australian Government agency. It was found that there were a range of complaints, typically associated with overall brightness and glare on the periphery of vision while working at the computer.

As a result of the study, a series of recommendations has been developed with regards to desirable horizontal and vertical illuminance levels and the preferred luminance characteristics of fittings. These recommendations were implemented at one site, resulting in a significant improvement in satisfaction and the elimination of severe or debilitating complaints. Qualitative data suggests that a productivity improvement may also have been achieved, but the available quantitative measures do not cover the area of potential improvement. A further significant result is that the lighting power density of the installation has been halved as a consequence of the upgrade, to only 5W/m^2.

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

Axel Bretzke

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Abstract

In the last years the producers have made remarkable progress with the efficiency of lighting. There are to notice conspicuous longer life time, better efficiency, changeable light distribution and therefore at all better planning factors. But those increase in efficiency needs more reinforce consideration, both, in standards and guidelines as well as in the concrete planning. Measurements of the illuminance in modernised schools of the city of Frankfurt show partly substantial exceeding towards planned data and the demanded valuing in the standards. Those exceeding cause relevant higher costs for investment and maintenance and can also lead to loss of comfort with screen-handling. Therefore new lighting-programs were controlled and tested in an pilot-project at the school “Helmholtzschule”. The experience was considered by the construction office in revised guidelines of the city. New lighting modernisation in schools of the city Frankfurt furthermore approve this substantial potentials of saving towards the precept in the newest standards. Different to the characteristic values in the DIN V 18599 with 5 to 10W/(m² 100lx) and DIN EN 12464, the guidelines for economical building (Leitlinien FFM) of the city of Frankfurt give lower specific values with 2 to 2,5 W/(m² 100lx), according to SIA 380/4 (switzerland) and LEE 1996. The guidelines for the German Association of Cities and Towns therefore give 2,5 to 3 W/(m² 100lx).

These values and the resulting low costs are proven for example in the following buildings:
In the new built primary school at Riedberg in Passivhouse-quality (Qp = 59 kWh/m²a) the classrooms with demand of 300lx attain a specific wattage for lighting of 5,6 W/m², the specific value is 1,9 W/(m² 100lx), over 400 lx are measured. In the comprehensive school “Schule am Ried”, after modernisation. the illuminance Em was calculated with an average illuminance of 368 lx with a specific value also under 6 W/ m². Despite of this optimised planning a average illuminance Em of 443 lx was measured after modernisation. Therefore the postulation of an maintenance-factor lower than 0,8 an (DIN EN 12464) is not necessary for optimised planning with lighting programs.
Another example is the lighting reorganisation of two gymnasia. In spite of their relevant height the specific values almost keep nearly at the guideline values.
Therefore the Departement of Energy-management starts a program of new lighting for further eight schools. With an optimised planning the lower costs for invest and maintenance results in a pay back time of only 5 to 10 years.

Introduction

A reduced power-consumption with standard lighting-quality is set objektive by the EU (Directive on Energy performance of Buildings - EPBD or EC-guideline 2202/91/EG). The potential is larger than estimated in standards and computation rules.

In the new Standard DIN 18599 part 4 you can find empirically established values about the lighting-efficiency for non residential houses. Comparing these values with the empirically established values for good lighting in the guide for electric energy of the country Hessen 1996 (LEE 1996) or weakend in SIA 380/4/LEE 2000, a substantial saving potential for power consumption and partly invest from 50 to 80% is to recognize.

The city of Frankfurt has already verified this potential since 2002 in a pilot-project and further projects. The results shall point out the economical potential during the restoration. The city of Frankfurt has therefore postulated the standard of the LEE 1996 in its guidelines for economic

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

building and has put them into the further practice. It was shown, that software and spreadsheet calculation according to standards are not suitable for an optimised planning. Also became considered the experience, that illuminance is not decisive for the positive evaluation of the illumination-quality alone.

Standard values

In table 1 of DIN 18599 part 4 the following specific values for Efficiency of lighting from evaluation of stock of buildings are given:

Table 1: lighting efficiency, DIN 18599/4

Light distribution	Relative light output downwards φ_u [-]	specific wattage with electronic ballast [W/m^2 100 lx]
direct	> = 0,9	5
direct/indirect	0,1 <= . . .< 0,9	6
indirect	0,1	10

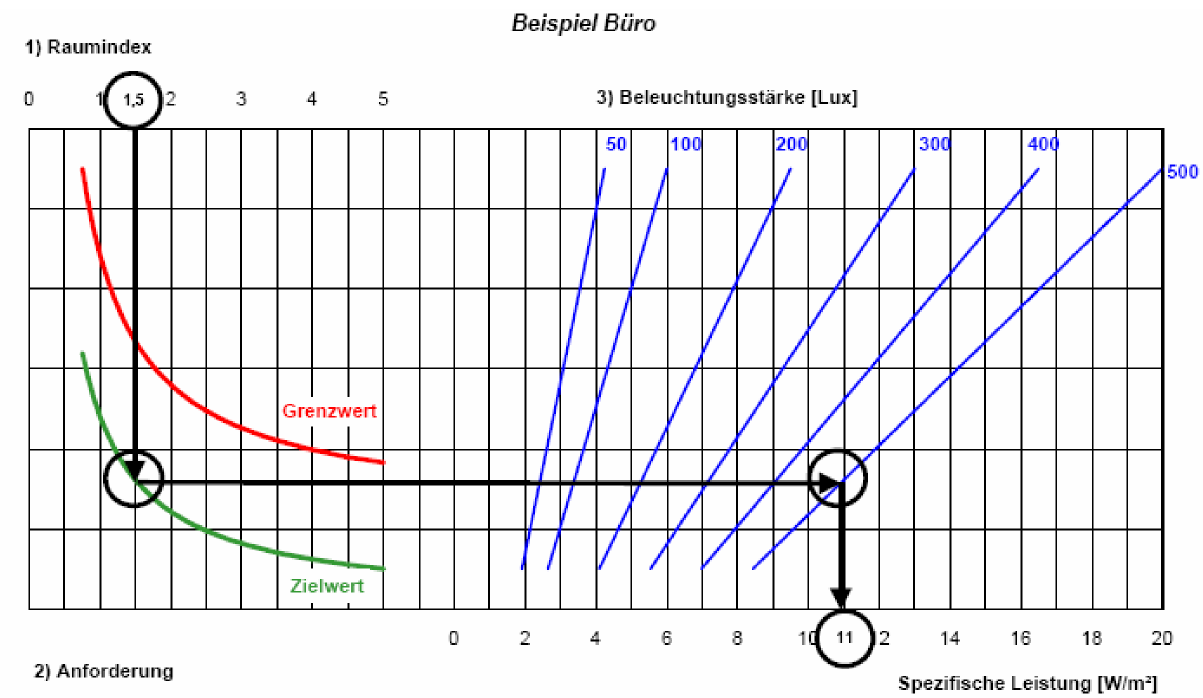


Fig. 1: specific wattage for lighting, lighting efficiency dependent on room index and illuminance, SIA 380/4 in: SIA etool (left: room-index)

The LEE 1996, reference on the empirically values after SIA 380/4 and new computations gives 2,5 W/(m^2 100lx) as limit value and 2 W/(m^2 100lx) as goal value.

Table 2: Table 2.5 in LEE 1996, fv use factor

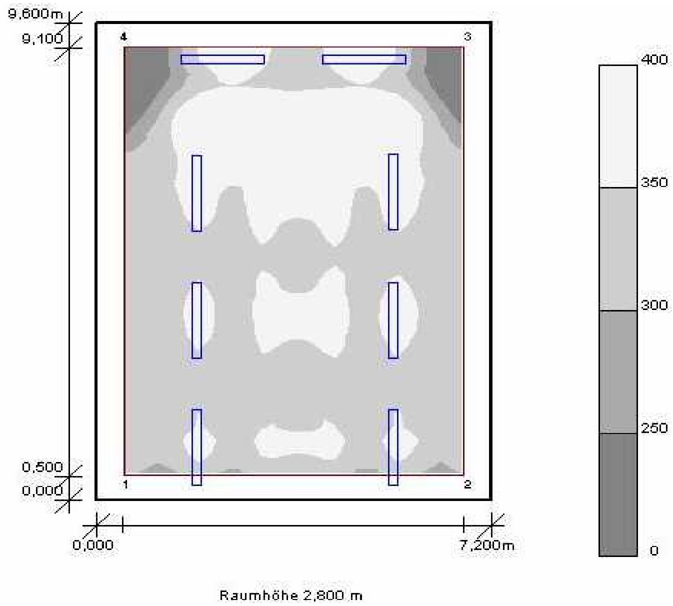
Limit Value	[mW/(m^2 lx)]	25 * fv fv <= 0,7
goal Value	[mW/(m^2 lx)]	20 * fv fv <= 0,7

Comparing these values with classic planning and the stock values according Fig. 1, the potential for saving (power and therefore power-consumption) is about 50 to 80%. Reduced invest in lighting also is a result (less luminaires).

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

Pilot project Helmholtzschule

In the project Helmholtzschule the city of Frankfurt has proven the capabilities of an optimised planning for the modernisation of a pilot Classroom with a standard modernisation in the comparison classroom.



Em in lx (*)	Emax in lx (*)	Emin in lx (*)	Emin/Em (*)	Emin/Emax (*)
339	452	128	1:2,6	1:3,5

*)... Nutzebene vermindert um 0,500 m Randzone

Fig. 2: lighting pilot-classroom, optimised with 8x35W T5 luminaires for demand 300 lx, 5,2 W/m^2, calculation with DIALUX, reflection 70/50/20, maintenance factor 0,8

The specific wattage of the lighting in the pilot classroom with eight T5 35W luminaires is 5,2 W/m^2. The standard after AMEV Bel2000, which is much better than the values of DIN 18599, is 8 luminaires with 58 W T8, resulting in a value of 7,3 W/m^2, experienced in the comparison classroom. The old classrooms had about 16 W/m^2 with 12 x 58W T8 luminaires. The default average illuminance of the DIN (300 lx etc.) were kept in both cases (Em 339 lx und 540 lx). The meassured illuminance showed a substantial excess over 20% against the planned values. This was also reported from other software, also in Switzerland. Despite of less illuminance, however the pilot room was evaluated as brighter and friendlier by the users, which confirmed the concept. This showed also, that, apart from the illuminance on utilizable level the choice of the light distribution- broad-radiating- as well as a small indirect portion by a laterally punched raster - can be also decisive (Fig. 3.

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

Fig. 3: lighting pilot-classroom (left): 5,2 W/m^2, 339 lx, comparison classroom (right): 7,3 W/m^2, 540 lx

Compared with a old lighting one can save 33% of invest (4 luminaires) and nearly 70% of power consumption.

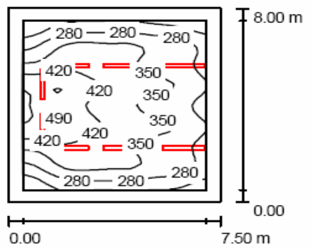
Therefore these defaults of the LEE 1996 were fixed in the technical standards of the building department of city of Frankfurt in 2001/2002. They were used and verified in further projects, for instance in the Passivhouse – primary school at Riedberg and the Comprehensive school "Schule am Ried".

Further Projects

"Schule am Ried"
For the reorganisation of these Comprehensive school there was placed value on an optimised, economical lighting. From the experience in the pilot-project Helmholtzschule the lighting was calculated with T5 luminaires, and reflection of 70/43/20. For a classroom of 60 m^2, 8 luminaires with T5 36/39W lamps (3200/3600 lm) are used. The illuminance Em, calculated with maintenance factor 0,95 as 343 lx, was measured with Em = 443 lx (Fig. 4 and 5). Therefore it was shown again, that lighting software shows relative conservative results to give a good warranty for sufficient illuminance. Table procedures in accordance with standards were not suitable for an optimised planning.

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m² 100lx)

Klassenraum - Einblattausgabe



Raumhöhe: 3.000 m, Wartungsfaktor: 0.95 | Werte in Lux, Maßstab 1:200

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g1
Nutzebene	/	343	139	520	0.40
Boden	20	267	111	465	0.42
Decke	70	48	23	67	0.47
Wände (4)	43	92	26	314	/

Nutzebene:
Höhe: 0.850 m
Raster: 16 x 16 Punkte
Randzone: 0.500 m
Beleuchtungsstärkeverhältnis (nach LG3:2001): Wände / Nutzebene: 0.237, Decke / Nutzebene: 0.139.

Leuchtenanordnungen

Typ	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	6	TRILUX 5041RSV-L/35 E Raster-Anbauleuchten Baureihe 504··· (1.000)	3600	39
2	2	TRILUX 5081W-RSA/36 E Raster-Anbauleuchten Baureihe 508··· (1.000)	3200	36
		gesamt:	28000	306

Spezifischer Anschlußwert: 5.10 W/m² = 1.49 W/m²/100 lx (Grundfläche: 60.00 m²)

Fig. 4: Schule am Ried, classroom 116, calculated values of illuminance an specific wattage

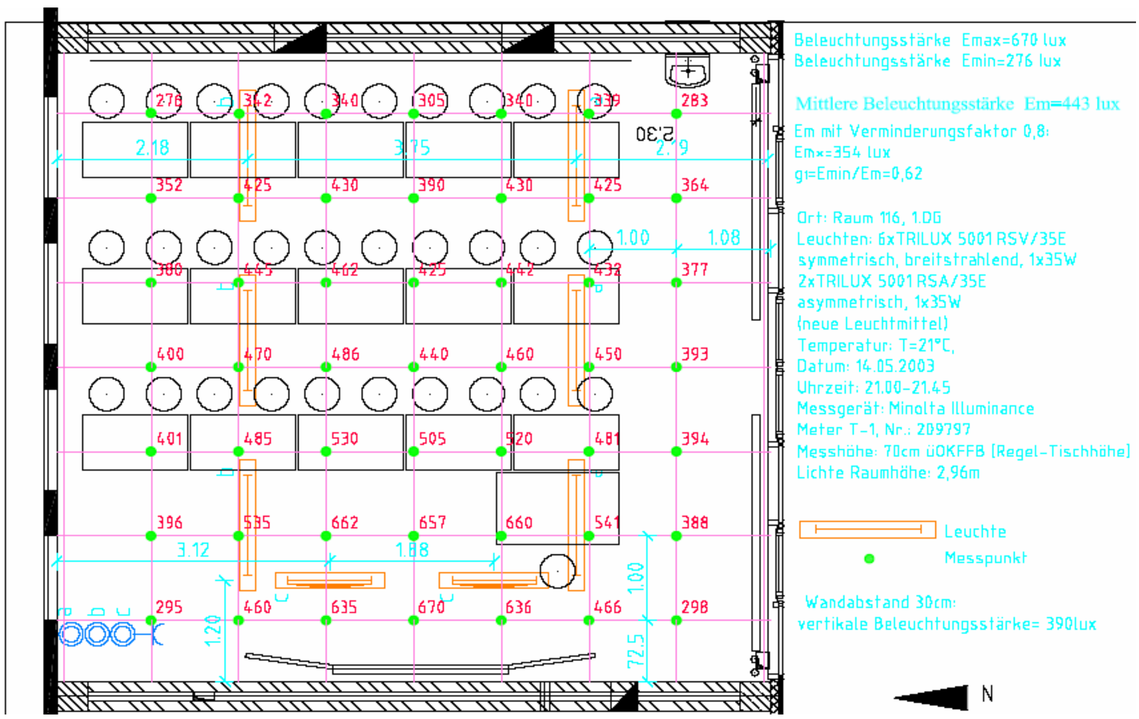


Fig. 5: Schule am Ried, classroom 116, massured values of illuminance

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

Fig. 6: Schule am Ried, classroom 116

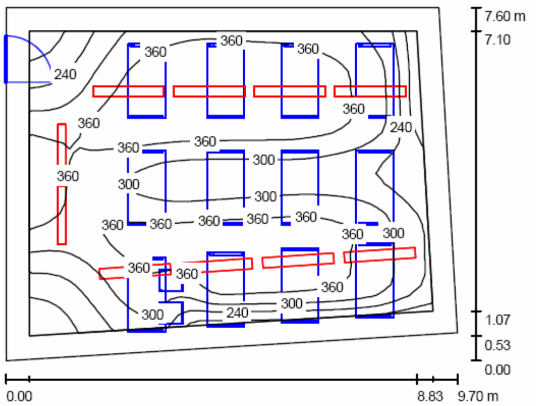
„Heinrich-Kromer-Schule", Satellite Riedberg

In the primary school at Riedberg the experiences from the preceding examples were considered. The defaults for a Passivhouse school with 120 kWh/(m^2 a) are very close, therefore also an optimized lighting planning was important. With T5 35 W, mirror raster three-gang luminaires with punched raster it was possible, to get an specific value of 5,6 W/m^2 for an average illuminance of Em 300 lx. Therefore each classroom of 69 m^2 gets 10 luminaires, two of them for the blackbord. The invest per light was typical, 100 € inclusive mounting. Also here the measured illuminance was higher than the calculated, despite the reflection and the maintenance factor were high computed.

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

Fig. 7: **School at Riedberg, Classroom**

Klassenraum - Einblattausgabe



Raumhöhe: 3.100 m, Montagehöhe: 3.100 m, Wartungsfaktor: 0.80 Werte in Lux, Maßstab 1:100

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g1
Nutzebene	/	327	129	418	0.39
Boden	30	192	50	317	0.26
Decke	90	126	38	2709	0.30
Wände (4)	60	109	26	304	/

Nutzebene:
Höhe: 0.850 m
Raster: 20 x 15 Punkte
Randzone: 0.500 m
Beleuchtungsstärkeverhältnis (nach LG3:2001): Wände / Nutzebene: 0.321, Decke / Nutzebene: 0.384.

Leuchtenanordnungen

Typ	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	2	TRILUX 5081W-RSA/36 E Raster-Anbauleuchten Baureihe 508··· (1.000)	3200	36
2	8	TRILUX 5261RSV-L/35+05261DG/1500 E Raster-Anbauleuchten u... (1.000)	3300	39
		gesamt:	32800	384

Spezifischer Anschlußwert: 5.53 W/m² = 1.69 W/m²/100 lx (Grundfläche: 69.41 m²)

Fig. 8: School at Riedberg, calculated illuminance and specific efficiency

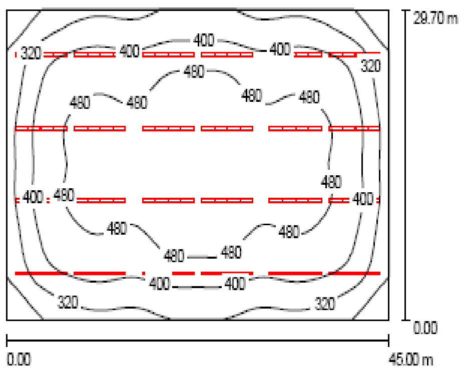
Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

Gym "Friedrich-Ebert-Schule" and "Wilhelm-Merton-Schule"

The old lighting in the Gymnasium of the Friedrich-Ebert-Schule had a specific value of 12W/m^2 but insufficient illuminance. After reorganization with a value of 7,9 W/m^2 a satisfying illumination with more than 400 lx was attained, despite a height of 7,5 m. For 1336,5 m^2, 96 T8 luminaires with-2x58W lamps were used. The measure has a pay-back period within 6 years, calculated with 1750h/a.

In the gymnasium of the "Wilhelm-Merton-Schule" the old lighting had a value of 48 W/m^2. The new lighting with 108 one and two flame T8- 58 W Mirror raster luminaires with EB reach a value of 9,74 W/m^2 with a requirement of 400 lx. This, although the gymnasium has a hight of 9,5 m and a bad reflection because of the wood-walls. The measure has a pay-back period within 3,5 years, calculated with 1000h/a .

Sporthalle Friedrich-Ebert-Schule - Zusammenfassung



Raumhöhe: 7.200 m, Montagehöhe: 7.200 m, Wartungsfaktor: 0.80 Werte in Lux, Maßstab 1:500

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g1
Nutzebene	/	421	169	559	0.40
Boden	55	408	170	544	0.42
Decke	78	180	85	256	0.47
Wände (4)	26	222	97	358	/

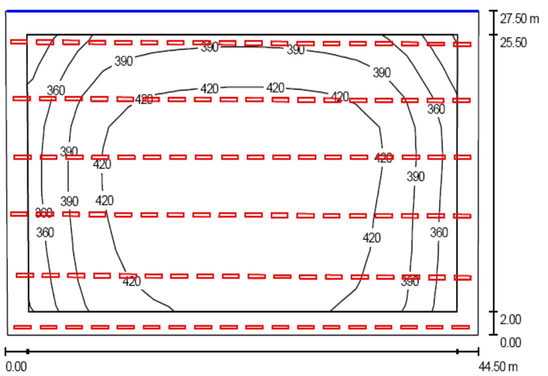
Nutzebene:
Höhe: 0.850 m
Raster: 32 x 16 Punkte
Randzone: 0.000 m
Beleuchtungsstärkeverhältnis (nach LG3:2001): Wände / Nutzebene: 0.524, Decke / Nutzebene: 0.427.

Leuchtenanordnungen

Typ	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	96	Kandem SA 11/2X58 EVG (1.000)	10000	110
		gesamt:	960000	10560

Spezifischer Anschlußwert: 7.90 W/m² = 1.87 W/m²/100 lx (Grundfläche: 1336.50 m²)

Sporthalle Wilhelm-Merton-Schule / Einblattausgabe



Raumhöhe: 9.000 m, Montagehöhe: 7.200 m, Wartungsfaktor: 0.72 Werte in Lux, Maßstab 1:347

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g_1
Nutzebene	/	408	299	444	0.73
Boden	25	372	174	445	0.47
Decke	70	95	58	118	0.61
Wände (4)	51	155	30	698	/

Nutzebene:
Höhe: 1.000 m
Raster: 17 x 9 Punkte
Randzone: 2.000 m
Beleuchtungsstärkeverhältnis (nach LG7): Wände / Nutzebene: 0.389, Decke / Nutzebene: 0.232.

Leuchtenanordnungen

Nr.	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	108	Kandem SA 11/2X58 EVG (1.000)	10000	110
		gesamt:	1080000	11880

Spezifischer Anschlußwert: 9.74 W/m² = 2.39 W/m²/100 lx (Grundfläche: 1220.31 m²)

Fig. 9 and 10: Gymnasium "Friedrich-Ebert-Schule" and "Wilhelm-Merton-Schule", calculated illuminance and specific efficiency

Best practice for lighting in Frankfurt schools, also standard in the directive with 2W/(m^2 100lx)

All projects

Economy, Reaching of the limit and goal values
The economic conversion of the specific values of the LEE 1996 with a goal value of 2 W/m2 100lx could be proven in the two school projects on adherence to the standard defaults of an average illumination Em = 300 lx.. Even with the two gymnasia with higher lighting requirements (larger height and worse reflection degrees) characteristic values were attainable in the range of the limit value of the LEE 1996 of 2,5 W/(m^2 100lx) with economic measures of reorganisation.

Further efficiency increase
Additional to the optimised planning of lighting also the daylight use and the occupancy dependent light circuit should be optimised. Automatic daylight systems are still not economically for application in schools with measured utilization periods between 400 and 1000h/a.
Therefore a central tracing disconnection was tested and used. It was shown to be as affective as an automatic control. Five minutes after end of the first school hour (approx. 8:30 am) for the first time in all classes the light is centrally and briefly switched of, beside of inner classrooms. Even in the winter at this time it is already sufficiently bright in order to be able to restart the light again if necessary. This is repeated in each break over the day till dawn. Surprisingly in the project there was no negative feedback to this tracing circuit. In relation to an automatic control the light is completely switched of if not necessary. To this the experience confirmed, that a good artificial lighting is no longer particularly noticed and switched of. This leads to the well-known phenomenon of the continuous use of lighting with automatic daylight control.

Further examples
Also newer projects within the office-buildings reach the characteristic values of the LEE 1996. The range of the specific wattage for basically the same task to see is however still astonishing and is from 5,0 to 14 W/m^2, even for ambitious energy savings buildings (Hoffmann/Voss).

Conclusions

The goal and limit values of the LEE 1996 and the standard of SIA 380/4 with 2 and 2,5 W/(m^2 100lx) are economically attainable with an optimised lighting. The defaults of the “guidelines for economic building” of the city Frankfurt, 2.5 and/or 2 W/(m2 100lx) as economic optimum were confirmed.
The investment costs for the realised projects are in the context of a good standard and clearly under the costs of a classical installation after standard calculation sheets. With optimised lighting the power (wattage) and current saving alone are 50 % and more in relation to a classical planning. The comparison with the characteristic data of the standard DIN V 18599 for the building stock with 5 to 10 W/(m^2 100lx) proves therefore a realistic saving potential in the existence of over 50% alone for power consumption. Also in relation to a good planning e.g. according to the defaults of the AMEV (BEL 2000) 20-30% can be still saved with an optimised planning. The illuminance of standards was kept in each case, the computed values became exceeded in each case. Safety impacts to the planning computations of the used lighting software are therefore not helpfull. By the selected mirror raster luminaires with EVG, laterally punched raster and high efficient lamps the users are satisfied with the illuminance and quality. Also the tracing circuit was surprisingly accepted. Oversizing of the lighting are not necessary, partly even unacceptable (AMEV BelBild 2002). The pay back period of a modernisation of old lighting in schools is 5 to 10 years, dependent on the useful hours per year..

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The implementation of Energy-Efficient Lighting in Flanders: "Groen Licht Vlaanderen"

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KaHo Sint-Lieven

Abstract
At the end of 2004, the project -**The Implementation of Energy-Efficient Lighting in Flanders:"Groen Licht Vlaanderen"-** was launched. The main objectives of the project are to stimulate the use of and the research on energy-efficient lighting, to accelerate the introduction of promising techniques through integration in design applications and to become a "centre of excellence" for efficient lighting in the Flemish region.

Introduction

In December 2002 the European Community published the European Directive on Energy Performance. Member States were obliged to have an integrated energy performance calculation by January 2006. The Flanders region recently implemented such an Energy Performance Regulation (EPR) to determine the energy performance in buildings. In the tertiary sector, lighting can represent a lot of the primary energy consumption. As mentioned in de brochure "20 tips voor een energievriendelijke school" (Ref. 3), lighting in schools can represent up to 73% of the electricity consumption; for offices the document "Kantoor 2000" (Ref. 4) states a mean electricity consumption of 27% for lighting with a huge deviation of 13%. That is why the EPR includes lighting calculations, as far as schools, offices and government buildings are concerned. This Energy Performance Regulation will increase the market for energy-efficient lighting applications. Companies involved in this technology will have interest to invest and grow on the Belgian and European market and can take advantage of this new situation.

It is important to know that the introduction of the Flemish Energy Performance Regulation will request an effort from the involved companies:

1. Product specifications need to be available on time and in the requested format for implementation in the energy performance calculation. Manufacturers will have to adapt the technical product documentation if necessary.
2. Due to the increased demand for energy-efficient products, companies will have to extend their product range with energy-efficient technology and accept the challenge for further product development.

Although a small progress in the implementation of energy-efficient installations was observed over the past years, there is still a tremendous potential for energy savings by using energy-efficient lighting systems in buildings and dwellings.
Application of the most recent day lighting knowledge (Ref. 5) and innovative lighting systems, combined with integrated smart controls, automatic sun blinds, dimming and occupancy sensors can lead to a minimal usage of artificial lighting.
Just as important as the innovative concept is the need for novel lighting installations consisting of energy efficient light sources, luminaires and auxiliary gears… all combined in an attractive design. This will result in a comfortable, dynamical and aesthetical installation which consumes less energy.

Groen Licht Vlaanderen

In 2004, the preliminary number of construction permits in Belgium was about 4200 for non-residential structures and about 28000 for residential constructions; the number of permits for renovations was about the same (See Table 1, Ref. 6)). In addition, for the first six months of 2005, the number of building permits in Flanders did reach the highest level since 25 years despite the increase in prices for building lots and the diminishing availability of lots. Since the Flemish region accounts for about 70% of the total number of construction permits one can explain the urge for promoting energy-efficient lighting installations in the region. In all these new-(to)-build constructions almost no efforts were undertaken to lower the energy consumption. The initiative for the Groen Licht Vlaanderen program was taken by the Flemish Passive House Platform, an organization involved in passive house building, as a result of the demand for energy-efficient electrical installations. Since the project fits in the program for Thematically Stimulation of Innovation launched by the Institute for the Promotion of Innovation by Science and Technology in Flanders (IWT, Ref. 2)) it is financially supported (80%) by the Flemish Government for a double period of 2 years. The daily work is managed by 1 fulltime co-worker at the technical university KaHo Sint-Lieven in Ghent (Flanders-Belgium) in a cooperation of the section Electronics and the Laboratorium voor Lichttechnologie (section Mathematics-Physics) at the department of industrial sciences. The guidance of the project is fulfilled by a consortium (Ref. 1), mainly consisting of lighting and non-profit companies providing the remaining 20% of the financing. Both the consortium, as well as the program, was given the name “Groen Licht Vlaanderen”.

Table 1: Construction Permits Belgium (1997-2004)

	2000	2001	2002	2003	2004 (a)
New Construction					
A. Dwellings					
# Constructions	26.607	24.839	23.796	25.170	28.169
# Dwellings	42.921	41.292	42.146	44.988	51.748
1. apartments	18.477	18.714	20.687	22.512	26.739
2. other dwellings	24.444	22.578	21.459	22.476	25.009
Habitation Area (m²)	5.115.296	4.870.955	4.506.097	4.848.735	5.380.437
B. Non-dwellings					
# constructions	6.396	5.487	4.550	3.881	4.264
Total volume (m³)	47.623.376	49.474.784	34.948.496	29.291.600	37.439.776
Renovation					
# renovations of dwellings	25.719	24.369	25.157	28.688	27.879
# renovations of non-dwellings	6.158	5.722	6.115	6.396	6.324
Regions in Belgium					
Brussels Capital Region	2,40%	2,30%	2,10%	2,40%	2,70%
Flemish Region	65,50%	67,60%	69,10%	69,70%	68,50%
Walloon Region	32,00%	30,10%	28,80%	27,90%	28,80%

(a): preliminary

The principal goal for Groen Licht Vlaanderen is to promote efficient lighting techniques in buildings and dwellings and force the go-betweens in construction (i.e. designers, contractors, architects, engineers, installers…) but also the clients (i.e. public sector, municipalities, institutions, organizations, educational institutes, industry, companies, commercial sector, proprietors…) to include energy-efficient lighting installations in their designs.

In addition, Groen Licht Vlaanderen wants to stimulate the Flemish innovators in developing low-energy lighting products or integrating these energy-saving light sources in design applications. We will assist and guide these product developers, federations and manufacturers by providing support in the means of technical help, partner search, guidance in innovation projects and assistance in search for grants and government subsidy. This will enforce the competition ranking of the Flemish companies involved in energy efficient lighting on the Belgian and European market. The promotion of innovation, networking and synergy will be necessary to maintain or improve the competitiveness of the Flemish lighting market.

Objectives

The detailed objectives for Groen Licht Vlaanderen can be described as follows:

1. Groen Licht Vlaanderen will address the needs for:
    a. transfer of knowledge to the general public. This can be realised by means of a website, a regular newsletter, a database for energy efficient applications and services, the participation to trade shows, publications of articles in technical journals and magazines and lectures and presentations at conferences and seminars.
    b. transfer of knowledge to the industry. A technology watch will investigate and report the new developments in the area of energy efficient lighting, both in Belgium (Flanders) and abroad. Seminars concerning energy efficient lighting and related techniques will be organized.
    c. confidence-building in the innovative developments. Objective and practical performance requirements for energy efficient lighting installations need to be formulated. New technologies will be demonstrated, evaluated and reported.
    d. promotion of energy efficient as well as aesthetical luminaires through the organisation of an exhibition
    e. integration of innovative lighting in residential acclimatization installations, building management, web-based installations, diagnostic tools, automation…
    f. stimulation of innovation by addressing the manufacturers in a pro-active way. They will be notified on the policy on funding and will be assisted in their search for grants.
    g. the European GreenLight Program will be promoted, future GreenLight Partners will be advised and assisted in the implementation of energy efficient lighting and the participation in the GreenLight Program

2. Economical target:
    a. the introduction of new Flemish innovations and design applications for energy efficient lighting should lead to the commercialization of the related products. An increase in sales and new opportunities for export should be generated
    b. a higher market share for energy efficient lighting equipment and installations in Flanders
    c. an increased added value for the Flemish companies specialised in energy efficient lighting equipment and – installations.

3. Aims for sustainable technological developments:
    a. the need for energy efficient lighting on the Flemish market together with the objective performance requirements should be recognized
    b. at least 3 acknowledged low-energy constructions should be ready for demonstration after 2 years (compared to a traditional building, the electricity consumption for lighting should be 4 times lower)
    c. a consensus document must be introduced concerning the performance requirements for the realisation of low-energy buildings, installations and components

4. Concrete synergies should be realised:
    a. cooperation of the architects and the innovators
    b. team-work in building teams for demonstration projects
    c. Groen Licht Vlaanderen will collaborate with the local federations and international organizations (e.g. GreenLight Program)
    d. a concerted action between the companies and the research institutes, between designers, manufacturers and distributors

Target groups

The go-betweens, represented as target group 1 in Figure 1, play a crucial role in the implementation of energy efficient installations but also in the transfer of information and knowledge from the manufacturers towards the clients. Furthermore, they are in the best position to give feedback to the inventors concerning the experiences and demands from the customers. Architects can control and thus shorten the need for artificial lighting by allowing an optimal daylight entrance in their designs, and can integrate smart control systems for dimming, occupancy detection and daylight admittance designed to reduce running costs, increase flexibility of space utilisation and maximize comfort.

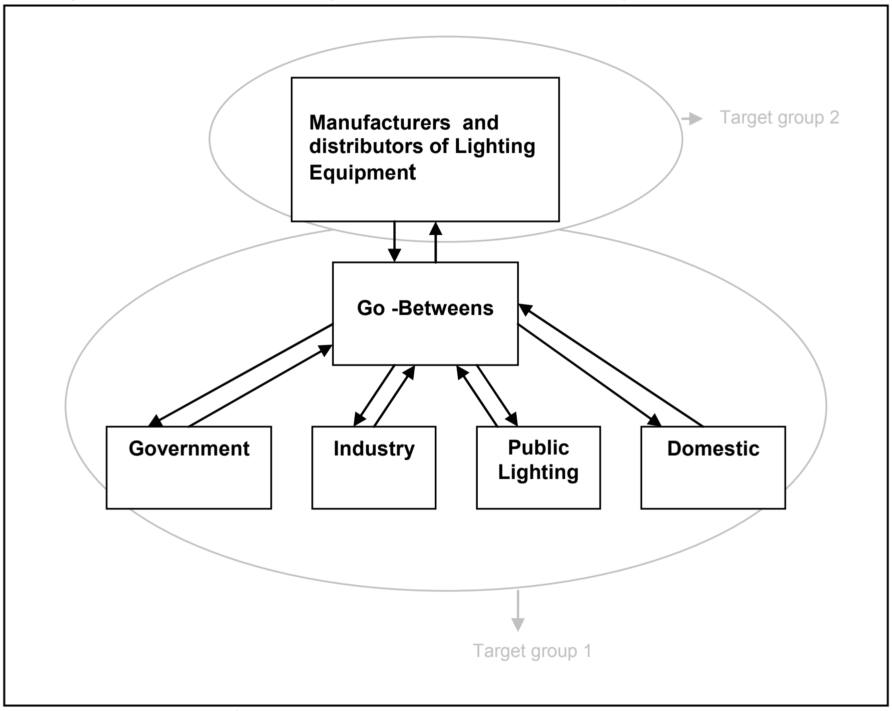

Figure 1: Target Groups

Flemish innovators, represented in figure 1 as target group 2, will also be encouraged in developing low-energy lighting products and integrating these energy-saving light sources in design applications. They will be supported by means of technical help, partner search, guidance in innovation projects and assistance in search for grants and government subsidy.

Target Group 1

Government
The Flemish administration is dealing with 1,4 million m² of constructions consisting of 640.000 m² offices; the Belgian institution “Regie der gebouwen” (Ref. 9) has 1180 properties (5,5 million m²) and 553 rented buildings (2,5 million m²). This leads to an immense energy saving opportunity since the electricity consumption for lighting may represent 30% and more. For schools it has been examined that about 73% of the electricity consumption is related to lighting. Meanwhile it has been decided that

the Flemish Government will, starting from 2006, spend 10 million € (Ref. 10) for renovations in schools in view of rational energy use.

Industry
For SME, the energy consumption for lighting is estimated around 30%-40%. Groen Licht Vlaanderen wants to involve the industrial maintenance services in the implementation of energy saving techniques in these small and mediate enterprises. For the large industry, lighting could represent at least 15% of the electricity bill, which seems relatively low but represents about 1TWh. Therefore the Flemish government created a contract, the so-called “Audit-convenant”, which will be the keystone for the promotion of energy-efficient use in the industry for the coming years. Based on an energy plan these companies will realise important energy savings and will help to achieve the Flemish Kyoto objectives.

Public Lighting
Although the consumption for public lighting remained on the same level over the past years, i.e. about 800 GWh (Evolutie van het jaarlijks elektriciteitsgebruik (GWh) voor buitenverlichting per sector, Ref. 7; Mira Achtergronddocument 2004 Lichthinder, Ref. 8), there is still an enormous potential for energy-savings in this area. In 2001, the official report from the Flemish Environment Agency (MIRA-T 2001, Report on the Environment and Nature in Flanders) stated that a 59% saving on the annual consumption for public lighting could be achieved by decreasing the number of burning hours in combination with the installation of energy efficient lamps.

Domestic
Based on estimates, it can be assumed that in Flanders, lighting in dwellings is responsible for about 10 to 15% of the total domestic electricity consumption. The major problem related to the promotion of energy efficient lighting is that private persons are difficult to address. People are more concerned about the ambiance and comfort which is created by the lighting installation. Energy consumption is only a minor concern. This explains why luminaires for incandescent bulbs are still very popular. Halogen bulbs are well-known and appreciated because they generate a warm-white light with good colour rendering. Since the first generation of energy-saving lamps was of poor quality and non-attractive, it will be an enormous challenge to change the attitude of most people and enhance the acceptability of (Compact) Fluorescence Lamps.

Target Group 2

A successful implementation of the EPR could also provide in an important number of advantages and opportunities for the manufacturers and distributors:
1. The growing demand for energy efficient, but more expensive systems, will lead to a better turnover and provide an added value for the business.
2. The request for high-quality energy-efficient products will tackle down the huge import of inferior overseas products.
3. New developments in energy saving products will fasten the market growth which will insure a faster payback of the investments and a growing profitability.

Since forecasts show a growing demand for innovative energy efficient lighting in residential, industrial and functional applications, it is obvious that Groen Licht Vlaanderen needs to urge manufacturers, distributors and product developers to continue to improve the quality of lighting fixtures.

Light Sources
Over the past years new Compact Fluorescence Lamps with good colour temperatures and nice shapes came on the market. However, action has to be taken in order to develop and market luminaires designed for this energy efficient lamps.
Another ambitious technology concerns the Light Emitting Diodes – LEDs (Ref. 11). Solid state lighting promises to save energy reduce maintenance and change our entire lighting structure. Although the technology may not yet be ready for general lighting use, each incremental improvement in its development opens doors to more applications where it can replace less efficient light sources.

Flemish lighting companies will have to contemplate on the possibilities for innovation in this area, to build expertise in this matter and to be prepared in replacing the complete incandescent (halogen included) bulb market. This evolution together with the intrinsic possibilities of dynamic and colourful lighting, will allow the LED technology to overrule the competition in interior lighting.
A similar observation can be made for gas discharge lamps (High Intensity Discharge - HID lamps). Miniaturisation and the introduction of low power versions (20W, 35W) offer new possibilities in the retail and domestic appliances. Nevertheless, further research for improved and faster start and restart is needed.

Luminaires
Developers of luminaires will have to focus on gears and on Light Output Ratio using high efficient reflectors and (holographic) diffusers. Secondly, the need for state-of-the-art low-energy lighting products will drive the manufacturers towards design luminaires, in demand by the architects.

Preliminary

During October 2005, proclaimed as the “Month of Energy” some members of Groen Licht Vlaanderen contributed to the session “Better Light” of the Passive House symposium. In the lecture “Optimization of Daylight Admittance” by Koen Govers (Cenergie) the importance of daylight in the design of buildings was discussed. The presentation of Jan Van Riel (Trilux) went into “The energetic, ergonomic and economic aspects of Industrial Lighting” and emphasized on the importance of a well-considered light design. Finally, Koen Goos (Etap Lighting) presented “Saving energy by Relighting”, focussing on relighting opportunities.

Groen Licht Vlaanderen addressed local authorities to participate in the Flemish regional initiative called Rational Use of Energy (RUE). Meanwhile, we convinced the authorities to re-introduce the grants for New- and Relighting. Furthermore, we play an important role in the second phase of the distribution of free CFL to households. We urged for the distribution of suitable lamps of high quality, accompanied by an information brochure. The kick-off for this initiative is scheduled May 2006.

In view of the new European standard EN-12464, some research was done on a new efficiency criterion for the specific power density for lighting. The most important issue in this work is the recognition of the effective task area including vertical areas like blackboards in schools, shelves in offices, libraries, shops and warehouses.

A proposal for a research project regarding efficient lighting in retail and shops was submitted. Shop lighting has some particularities: a lot of vertical task areas and shelves have to be illuminated, low storage temperatures influence the lamp efficacy and the assessment of colours by the client is extremely important. Furthermore, we want to investigate and model the impact of the lighting installation on the power consumption of air-conditioning and refrigerated displays (Ref. 12).

Conclusions

In the next 3 years, Groen Licht Vlaanderen will stimulate the use of and the research on energy-efficient lighting in dwellings and buildings. It will also focus on the integration of new, innovative and energy efficient lighting technologies in design fixtures. An accelerated introduction of promising techniques will be accomplished by knowledge transfer. This will realised through publications, newsletters, a website and demonstration projects.

In addition Groen Licht Vlaanderen wants to realize a better awareness of the consequences of a well-considered strategy for lighting and related technologies. A better description of performance needs and requirements regarding the electrical lighting installations is essential for this achievement. Groen Licht Vlaanderen wants to become a ”centre of excellence” for efficient lighting in the Flemish region

Last but not least, Groen Licht Vlaanderen wants to realise a higher competitiveness of the Flemish lighting industry in Europe by means of innovation, networking and synergy.

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The results of the GreenLight Programme and the extension in the new EU Member States and Candidate Countries

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Abstract

To convince end-users to adopt efficient lighting technologies and systems and achieve a long lasting market transformation, the European Commission launched in 2000 the European GreenLight programme. It is an on-going voluntary programme whereby private and public organisations (referred to as Partners) commit to adopting energy-efficient lighting measures when (1) the cost of these measures is repaid by the associated savings and (2) lighting quality is maintained or improved. GreenLight Partners report annually on their achievements within the programme. In return for their commitment, not only do they benefit from large savings, but they also receive broad public recognition for their effort in protecting the environment. So far, GreenLight has gathered more than 280 public and private organisations, including major players. Several lessons have been learned at all stages of the GreenLight process.

At the marketing stage: often energy savings alone do not constitute a sufficient reason for companies to join GreenLight. Public recognition benefits have proven to be effective additional arguments to convince them, including the fact to be seen as environmental ‘champions”. Arguments related to indirect productivity increase would also be decisive if they could be scientifically demonstrated.

In the upgrading process, GreenLight Partners need a user-friendly lighting audit procedure which they can easily follow to quickly identify which spaces can be upgraded and which cost effective measures can be applied. Complex material does not get used. Information gathered within GreenLight show that there is a need to develop further rules of thumb, simple lighting quality assessment procedures, and lighting energy benchmarks for other spaces than offices (including average and best practice figures in W/m2 or kWh/m2). The final decisions are often take at high levels and the information presented to the senior management as to be simpler and based on economic terms.

Finally, in the GreenLight progress monitoring, the main issue was to provide Partners with an extremely simple form to report on their achievements. This form currently consists of one page per facility. It contains a short description of the baseline and the post-installation lighting conditions. The Commission has been assisted in the implementation of GreenLight by the energy agencies (or similar organisations) of 26 European Countries, who had a fundamental role in promoting the GreenLight at national and regional level.

Over 1000 buildings have been upgraded in the GreenLight programme, offering a very large set of examples of efficient lighting solutions in the different sectors (schools, offices, airports, supermarkets, etc.). The paper present the main results of the GreenLight programme, and the main lessons learnt.

A new project supported by the Intelligent Energy for Europe Programme has been started at the beginning of 2006 to promote the GreenLight Programme in some of the new Member States and Candidate Countries.

The results of the GreenLight Programme and the extension in
the new EU Member States and Candidate Countries

Introduction

Lighting electricity use in the European non-residential sector represents more than 160 TWh/year[1]. Major energy savings can be achieved. Examples from the field have shown that between 30% and 50% of electricity used for lighting could be saved investing in energy-efficient lighting technologies. In most cases, such investments are not only profitable but they also maintain or improve lighting quality.

To pull the demand for efficient technologies, the European Commission (EC) launched in February 2000 the European GreenLight Programme. It is an on-going voluntary programme whereby private and public organisations (referred to as Partners) commit to adopting energy-efficient lighting measures when (1) the cost of these measures is repaid by the associated savings[2] and (2) lighting quality is maintained or improved. In return for their commitment, not only do these Partners benefit from the savings, but they also receive broad public recognition for their effort in protecting the environment. The full details of the GreenLight Programme, including obligations and rewards, are available on the programme web site at www.eu-greenlight.org.

In 2001, after nearly one year of operation, the EC reported that 18 organisations had joined the programme as Partners and that 28 companies in the lighting business had committed to acting as GreenLight Endorsers. Endorsers support Partners in their efforts to reduce lighting consumption. GreenLight was also said to have gained public support from national energy agencies and similar organisations (referred to as Promoters) in 26 European countries. A number of suggestions were also given to keep GreenLight growing (Berrutto and Bertoldi 2001).

At the time of this writing, in March 2006, five years have elapsed since the first GreenLight progress report. More Partners and Endorsers have joined GreenLight. First savings estimates have been possible and public recognition has taken shape. These results are detailed in the present paper.

Progress monitoring

The GreenLight programme expects its Partners to report annually on their own achievements within the programme.

At the beginning of each year, Partners shall report their facilities that were upgraded, or newly built, according to the GreenLight Guidelines during the year before (yearly progress). The Partner shall also report their facilities for which upgrade is foreseen in the year to come (yearly mission statement).

A standard reporting form is provided by the EC for that purpose. This form consists of one page per facility. It includes the amount of investment, the energy saved, and the cost-effectiveness of the investments. It contains also a short description of the baseline and the post-installation lighting. If the form concerns an upgraded facility, the baseline is the existing lighting before the upgrade. When the form regards a new facility, the baseline is the conventional lighting to which the chosen energy-efficient lighting was compared. In this case, the baseline is in general the less efficient lighting solution that Partners were proposed as cheaper alternative by their lighting contractors.

Although GreenLight information resources (www.eu-greenlight.org) contain references to the International Performance Measurement & Verification Protocol (www.ipmvp.org), there is no obligation for Partners to follow any specific protocol to assess their energy savings. In practice, the large majority of them preferred to calculate their energy savings by simply using nameplate wattages and assumed operating hours. A few performed short-term in-situ measurements of energy consumption, in particular when control systems had been installed. But so far, none of them has undertaken 6- or 12- month post- and pre-monitoring.

[1] Estimates vary depending on source.

[2] GreenLight applies to 50% of the eligible upgrades. Eligible upgrades are those yielding an Internal Rate of Return above 20%.

Once filled, the reporting form shall be signed by the person of the company responsible for implementing GreenLight (so-called GreenLight Manager). The form shall then be sent to the European Commission Joint Research Centre[3] (JRC). The JRC is responsible for monitoring GreenLight progress.

The JRC also checks that reported savings are consistent with the baseline and post-installation lighting characteristics. It also controls that these latter characteristics are themselves consistent with realistic lighting practices (e.g. technological characteristics conform to the range of current existing technologies; operating hours and power densities in W/m^2 consistent with other sectorial benchmarks). This cross-checking has proved to be useful to spot anomalies. It can be complemented by spot visits of lighting installation by GreenLight Promoters. Systematic verification by independent third parties of the information published in GreenLight reports is not foreseen.

More comprehensive, longer reporting forms would obviously provide further ways to check the accuracy of the reported data. However, the first experience with a multi-page reporting form turned out to be unsatisfactory according to most Partners who found the form too demanding (JRC 2002). The form was subsequently reduced to a minimum to be acceptable by all users.

In an attempt to facilitate further the reporting process, the form was made available on the GreenLight web site in a fill-and-print format. This format provides automatic calculations and pull-down menus with list of possible technology choices.

Also, the few Partners wishing to use their own in-house reporting format have so far been allowed to do so.

Results

By March 2006, a total of 285 Partners signed the GreenLight partnership, thereby committing to adopting energy-efficient lighting practices in their premises (table 1). This represents more than a 14-fold increase compared to the first progress report (Berrutto and Bertoldi 2001), and during the last years of operation the number of Partners almost doubled. It confirms the observation made in the last report that the rate of registration was steadily increasing. The objective then mentioned of getting 300 signatures by the end of 2005 is almost reached.

Partners' size varies to a large extent. Some like Johnson & Johnson, McDonald's, IKEA or Carrefour, are multi-national groups with more than a million square meters. Others represent large cities such as Helsinki, Turin, Lyon, Hamburg, etc.. Other like Luvinate or Berchidda are small towns with a few kilometers of illuminated roads and less than 10 communal buildings (e.g. city hall, schools, sport hall). Others like Beerse Metaalwerken (industry) or Terres & Eaux (retail) have one building only, representing less than 5000 m^2.

> McDonald's joined GreenLight for their 5,500 restaurants in Europe (average size: 350 m^2). Five hundred restaurants were expected to be remodelled in 2002 while the same number should be newly built. On average, in each restaurant, lighting installed power will pass from 9 kW to 8 kW, representing savings of 6,667 kWh/year.

The total area covered by all Partners taken together is subject to caution. Despite all the measures taken to lighten GreenLight reporting requirements, not all foreseen Partners' reports have been

[3] The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

received yet. The rate of response is currently about 67 %, which prompted the EC to send reminders to late Partners.

Considering all received GreenLight reporting forms, total reported savings amount ca. 100 GWh/year, which corresponds to an abatement[4] of approximately 50000 tCO_2. Around 85% of these savings were achieved within buildings. The rest arose from street lighting upgrades (installation of flux dimmers).

As the list of Partners shows, various business fields were covered: Commercial, educational, healthcare, hotel, industry, leisure/sport, transport, etc. In the hotel sector, barriers to introduce energy-efficient lighting were found to be particularly severe due to strong habits of using halogen lamps. In general most upgrades concerned office spaces.

> In Norway, Statoil joined GreenLight in January 2001. As part of their commitment, they installed occupancy controls in their research centre. These controls turn off the lights once they have failed to detect occupancy for a set time. When occupancy is detected, they switch the lighting on again. Previously, the lights remained on the whole day in all offices and laboratories with a common switching system. This was a waste of energy given that occupancy patterns were intermittent and unpredictable. Lighting electricity savings amount 219,000 kWh/year (Internal Rate of Return of the investment: 40%.)

There are currently more GreenLight Partners in the public or semi-public sector (about 57% in the pubic sector) than in the private sector. While in Sweden, public organisations were said to be more incline to sign up for GreenLight than private companies, Austria, Greece, and Italy reported difficulties with public institutions. This has recently changed in Italy and Austria where many small town have signed up for street lighting projects. In Austria, public institutions said they could run into legal uncertainties if they would join a voluntary programme, this seems to have changed. In Greece, public organisations were said to have scarce funding and almost no possibility for Third Party Financing.

Generally speaking, the lack of capital and the inability to get financing for projects are well-known key barriers to energy efficiency investments. While in GreenLight most upgrades were self-financed by the Partners, several projects were also funded through Third Party Financing (TPF), especially for street lighting.

> In Italy, the city of Sassari installed a centralised dimming system to reduce its street lighting levels and thus its energy consumption and light pollution during periods of the night where traffic is lower. The city signed a "paid from savings" contract with the power control manufacturer and the installer. These financed up-front capital improvements in exchange for a portion of the savings generated. Besides providing tele-control capabilities, and thus easier maintenance, their system is claimed to have provided 1,855,385 kWh/year lighting electricity savings. The reduction of electricity use in the areas covered is ca. 30%. An estimated 172,551 Euro/year are saved and the investment has a payback time of 3 years and an Internal Rate of Return of 33%.

GreenLight investments use proven technology, products and services which can reduce lighting energy use by 30% to 50%, earning Internal Rates of Return (IRR) above 20%. GreenLight upgrades have covered the range of energy-efficiency measures described on the GreenLight web site[5], e.g. replacing general lighting service incandescent bulbs or high pressure mercury lamps; installing occupancy linking control systems or light flux regulators; etc.. In many cases, the substitution of magnetic ballasts with electronic ballasts on an existing installation, also proved to be profitable.

> In Portugal, GreenLight Partner Sonae Imobiliária upgraded the Centro Colombo covered car park, one of the largest in Europe, by substituting the magnetic ballasts with electronic ones. These operate fluorescent lamps at higher frequencies and offer significant advantages compared to magnetic ballasts, inter alia lower power losses. After measurements, they claimed to have saved 400,838 kWh/year which corresponds to a 11.5% reduction of electricity use in the areas covered. Energy cost savings amount 23,814 Euro/year. The Internal Rate of Return of the investment is 20%.

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[4] CO2 reduction is given only on an indicative basis and was calculated using common carbon intensity across all countries (500 gCO2/kWh).

[5] http://www.eu-greenlight.org/What-to-do/what1.htm

This example is now followed by many other partners such as multi-storey car parks, airports, football clubs, etc. Several upgrades were also undertaken which implied to change the complete lighting installation, including luminaires, albeit the fact that such a measure often earned rates of return below 20%. Some Partners somehow surpassed their GreenLight commitment.

In their Madrid headquarters, GreenLight Partner Gas Natural replaced the incandescent fixtures with modern luminaires for compact fluorescent lamps. Lighting electricity savings amounted 20,217 kWh/year which corresponded to 1033 Euro/year savings in running costs (payback time of the investment: 3.5 years). But Gas Natural's commitment to energy efficiency surpassed GreenLight requirements. They undertook a major energy-efficient renovation of their office lighting, although the associated payback time would be ca. 8 years. The old egg crate louver luminaires were replaced with modern parabolic troffers, doubling the luminaire efficiency, and improving glare and reflections control. The original halophosphate T8 lamps powered by high-loss magnetic ballasts were replaced with tri-phosphore T8 and electronic ballasts, thus improving colour rendering, suppressing flicker, facilitating the maintenance, and increasing further the lighting system efficiency. As for the general manual switch, it was replaced by localised switches offering better control to users. All together, these upgrades reduced lighting power density ($W/m^2/100lx$) by a factor of 4, while doubling illuminance levels, up to current recommendations.

A number of partners also installed the newer T5 technology resulting in large energy savings.

In Greece GreenLight partner TIM Refurbishment of 4 administrative buildings. In the building in Kifissias Ave the treated area is 12,760 m^2 offices + 25,600 m^2 underground garages.
The following actions have been implemented:
Offices
- Change all *(1684)* 4x18W (T8) conventional ballast fixtures to 4x14W (T5)
- Introduce local light sensors around T5 fixtures and perform dimming in the windows zone.
- Change conventional ballasts of *(1612)* 2x18W PL fixtures to electronic

Underground Garages
- Change ballasts from conventional to electronic on *(358)* 2x58W fixtures
- Introduce timers

Estimated cost 195,000 € and savings 492,000 kWh/yr and 83,636 €/yr
At the Operations centre (Athinon Ave) treated area is 9,400 m^2 offices + 8,000 m^2 underground garages
The following actions have been implemented:
Offices
- Change all *(1340)* 4x18W (T8) conventional ballast fixtures to 4x14W (T5)
- Introduce local light sensors around T5 fixtures and perform dimming in the windows zone.
- Change conventional ballasts of *(112)* 2x18W PL fixtures to electronic

Underground Garages
Change ballasts from conventional to electronic on *(170)* 2x58W fixtures
Introduce timers
Estimated cost 96,000 € and savings 314,250 kWh/yr and 27,341 €/yr
Results of the Entire project
- Estimated cost 292,000 €
- Treated area 55,760 m^2
- Savings 806,250 kWh/yr and 110,977 €/yr
- Energy savings for lighting 40%
- Payback time 2.7 yrs

Energy savings are specific to each lighting installation, depending on the installed technologies, the operating hours, the occupancy pattern and other factors. Sometimes GreenLight upgrades can be very simple, as simple as commissioning one control system.

While joining the GreenLight programme, SAS Norway undertook a survey of their building and exterior spaces. They hired a consultant to propose actions and calculate the energy savings. They realised that, by simply tuning up the existing bus system, they would save 30% of their lighting electricity use. They managed to do it themselves and since the building has separate measurements on each of the electrical distribution systems' main risers, it was easy for them to measure the electricity consumption before and after the bus system was optimised. Savings amounted 813,280 kWh/year. The investment was reimbursed in a few-month time.

By joining GreenLight, the companies have made good business sense. They found opportunities that resulted in environmental improvements and increase profits (by reducing costs) at the same time. GreenLight Partners have had direct benefits by saving money and in most cases improving working conditions.

In Belgium, GreenLight Partner Beerse Metaalwerken nv replaced the standard high pressure mercury lamps of their workshop with 26-mm diameter fluorescent lamps. They also installed a control system to dim the lamps' output in response to daylight availability. In their offices, they replaced the 38-mm diameter fluorescent lamps with 26-mm diameter lamps. All new lamps are geared with electronic ballasts. Not only did they saved 24,919 kWh/year but they also significantly improved visual conditions. They estimated that total running cost savings exceeded 7,000 Euro/year, taking into account the gains in productivity, (as estimated by the company itself).

GreenLight Partners have also had indirect benefits resulting from the growing attention of consumers and investors, which will increase their opportunities on the markets. Their ability to deal successfully with environmental issues may be considered as a credible measure of management quality. This supposes however that ad-hoc recognition and advertisement is given to their achievements; a point on which the EC and the national Promoters put emphasis during the second year of the programme.

Partners' rewards

During the last year, GreenLight public recognition has taken shape and the programme has gained public image. National Promoters had several articles published in the business press and technical magazines. The programme was presented in various fairs and conferences across Europe e.g. Pollutec in France, Valo 2001 in Finland, Light+Building in Germany, IEECB'04, etc. Publicity was also carried out through direct mail, local information meetings and the internet.

A plaque was designed to allow Partners to show their responsible entrepreneurship to their clients. A new brochure was distributed to potential Partners with several GreenLight success stories inside, presented in a clear, simple, and vivid way. Indeed case studies have been found to be very useful to convince peer companies to join.. The brochure is available in English, French, German and Italian and translations are foreseen in other languages. It was also distributed to various media and to the national Promoters for distribution within their respective country.

Figure 1 example of GreenLight plaque on Partner's Building

The results of the GreenLight Programme and the extension in
the new EU Member States and Candidate Countries

The Commission introduced a European award for particularly active and successful Partners and Endorsers. In the first year, 2002, that the award was established, the GreenLight partner award went to Johnson & Johnson.

> The healthcare company, Johnson & Johnson, was the first organisation to join the European GreenLight programme in 2000. In their Janssen Pharmaceutica facility in Belgium they have performed a relighting study for 75% of their 410,000 m² workspace. The actual relighted surface amounts 62,000 m². All new facilities are equipped with daylight- and occupancy-sensors, 26mm diameter fluorescent tubes with high efficiency ballasts and reflectors. In addition to less cooling needs, lower maintenance costs and better working conditions for employees, they reported 1,240,000 kWh/year savings; a reduction of electricity use in the areas covered of 40%; and energy cost savings of 62,000 Euro/year. Payback times for their investments varied from1.5 to 6 years depending on the project. Corporate Energy Director Harry Kauffman said: "We see the European GreenLight Programme as increasing the awareness within our companies in Europe and providing technical information and tools to accelerate our lighting upgrades."

Award Winner Partners in 2003 were:

1. Statoil (Norway),
2. Apoteket AB (Sweden), Retail sector
3. Comune di Trezzano Rosa (Italy), Public administration
4. Lorentz Casimir Lyceum (the Netherlands), School
5. Monte dei Paschi di Siena (Italy), Banks
6. Neukauf Merz (Germany), Retail sector.

Award Winners Partners in 2004 were:

1. Athens International Airport (Greece), Airport
2. Carrefour Italia (Italy), Retail sector
3. City of Hamburg (Germany) Public administration
4. City of Helsinki Educational Department (Finland), schools
5. City of Zurich (Switzerland), Public administration, office buildings
6. Dolce & Gabbana (Italy and Germany), Retail sector and office building
7. Futebol Clube do Porto (Portugal), Football stadium
8. Gemeente Sittard-Geleen (The Netherlands), Public administration, office building
9. Groupe Casino (France), Retail sector
10. DnBNOR ASA v/Vital Eiendom AS (Norway), office building

Award Winners Partners in 2005 were:

1. San Paolo IMI (Italy)
2. Provincia di Reggio Emilia (Italy)
3. TIM (Greece)
4. Auchan (France)
5. Q8 (Denmark)
6. Centocor (the Netherlands)
7. Halliburton (Norway);
8. EDP (Portugal)
9. McDonald's (Europe)
10. Wipark (Austria)

Award Winners Partners in 2006 were:

1. City of Oslo (Norway)
2. COOP (Italy)
3. Gates Europe nv (Belgium)
4. Hospital Universitario Virgen de las Nieves de Granada (Spain)
5. Nyborg Municipality (Denmark)
6. Philips (The Netherlands)

7. Piraeus Bank (Greece)
8. Servicio Extremeno de Salud (Spain)
9. SP-Trätek (Sweden)
10. Stadt Graz (Austria)
11. Stadt Frankfurt am Main Hochbauamt (Germany)
12. swb Netze Bremerhaven (Germany)
13. Vodafone Portugal (Portugal)
14. Zehnder Group Produktion Graenichen (Switzerland)

Technical support to Partners has continued. The GreenLight web site has been continuously updated by the EC Joint Research Centre, with contributions from the Promoters. The number of GreenLight Endorsers has grown to 149. Endorsers are committed to offering technical support to registered Partners.

Discussion and lessons learned

There is no correlation between the size of the countries and the number of Partners per country. As an example, Germany (10 partners) and UK (3 Partners) count a limited number of partner each. This is less than in Belgium (35 Partners), Norway (14) and Sweden (8). Except for a few cases, this result has been largely due to varying approaches for starting the implementation of GreenLight in each country. With its first positive results, the programme has gained the confidence of more Promoters[6] (including in Candidate Countries). It is now being expanded in most countries and the number of Partners shall continue to rise, especially in the largest member states.

European countries with no Promoter, i.e Luxembourg, have not received information on GreenLight whatsoever. Thus they did not count any Partner. Ireland was in the same situation, however recently the national promoter activity have very rapidly found new Partners.

The situation has been somehow similar in Denmark where promotion campaigns were not foreseen. Four Partners registered in Denmark recently thanks mostly to a Danish-based lighting consultant which was very active. In Belgium very active Endorsers have been key to the rapid success in this country. These companies provided some of their clients with free audits and offered them to fill the GreenLight reporting forms. In some cases, the endorser has also provided financing, acting as an ESCO. The effect of their environmental responsibility also touches upon their economic partners. They convince their supply chain to adhere to the GreenLight principles.

[6] List of GreenLight Promoters as of end of 2004: Austria (EVA: Austrian Energy Agency); Belgium (Ministère de la Région Wallonne; Centre Urbain/Stadswinkel asbl; Ministerie van de Vlaamse Gemeenschap); Bulgaria (EnEffect); Czeck Republic (SEVEn: the Energy Efficiency Center); Denmark (ENS: Danish Energy Authority); Estonia (OPET Estonia); Finland (MOTIVA: Energy Information Center for Energy Efficiency and Renewable Energy Sources); France (ADEME: French Agency for Energy Management and Environment); Germany (DENA: Deutsche Energie-Agentur GmbH; PTJ: Forschungszentrum Jülich GmbH; Berliner Energieagentur GmbH: Saarländ Energy Agency); Greece (CRES: Centre for Renewable Energy Sources); Hungary (Energy Centre Hungary); Ireland (Sustainable Energy Authority of Ireland); Italy (FIRE: Italian Federation for the Rational Use of Energy); Latvia (EKODOMA); Lithuania (Lithuanian Energy Institute); The Netherlands (NOVEM: Netherlands Agency for Energy and the Environment); Norway (Lyskultur); Poland (KAPE); Portugal (ADENE: Agência para a Energia); Romania (ARCE - Romanian Agency for Energy Conservation); Slovakia (Slovak Energy Agency); Slovenia (Jozef Stefan Institute - Energy Efficiency Centre); Spain (IDEA: Institute for Energy Saving and Diversification); Sweden (STEM: Swedish National Energy Administration); Switzerland (SFOE: Swiss Federal Office of Energy); UK (ECA Support Programme Manager).

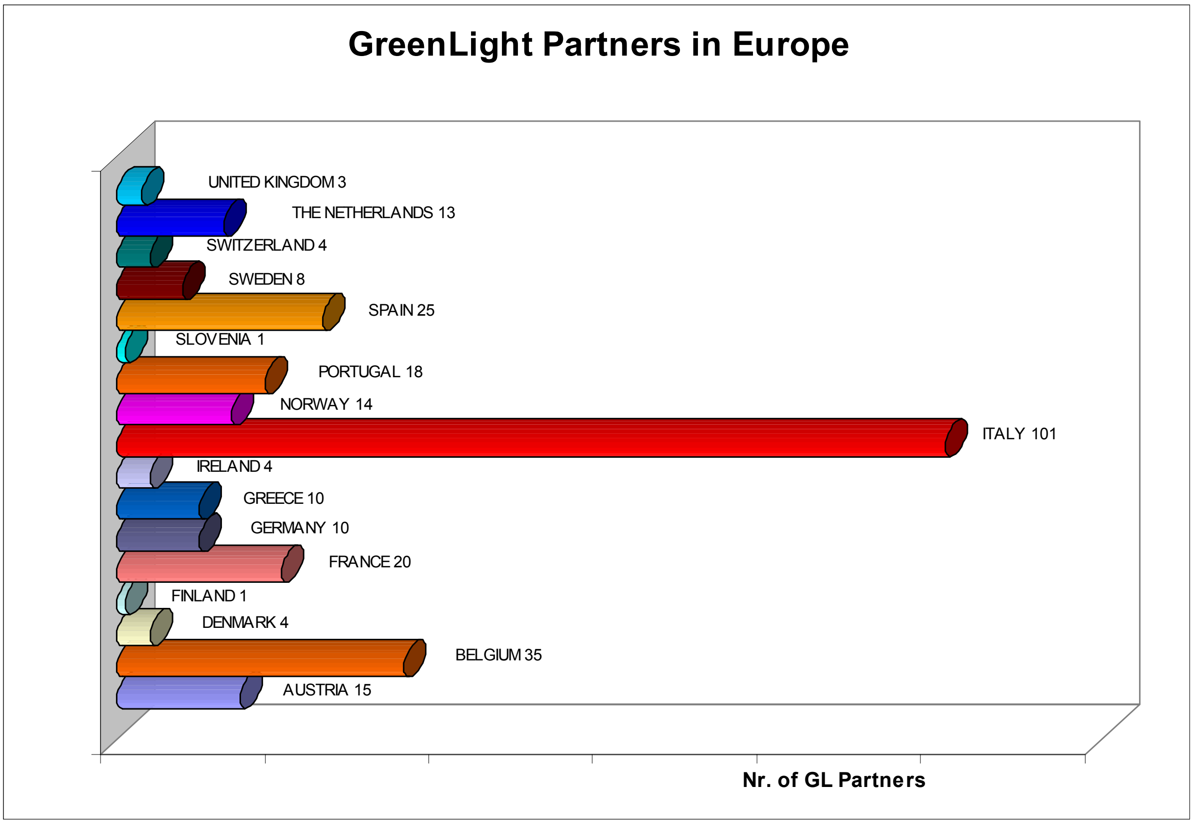

Figure 2: GreenLight Partners in Europe per country at 1.4.2006

In all the other Member States, plus Norway, the national Promoters have agreed under the terms of a SAVE contract to at least perform pilot GreenLight upgrades in 5 different organisations. This project began on 30 December 1999 and ran for 23 months. Its main objective was to show in 12 countries the merits of the ten starting European GreenLight Programme. A second SAVE contract to support national promoters started in 2002 and ended at the end of 2003.

In France, significant energy-efficient lighting initiatives had not taken place in the non-residential sector before GreenLight started (NOVEM 1999). The Promoter preferred to wait for the completion of the first GreenLight retrofits, until the end of the above-mentioned project i.e. early 2002, before promoting GreenLight more extensively. The same decision was taken in The Netherlands, Greece, Austria and Finland. The Promoters in all these countries reacted positively to the first GreenLight results. They decided to start marketing the programme more extensively in 2002. Since then the programme has taken off in all these countries, and in particular in Austria, The Netherlands and Greece.

Another barrier specific to France, Finland and UK was the fear of the word ‘commitment’. The fear of humiliation if a company should fail deterred some companies from joining. In the UK context, the explicit or implied undertaking of a commitment has substantial legal standing, and provided a significant issue for some of the companies contacted.

To overcome that barrier, the Partners guidelines were revised. A company can now join the GreenLight Programme only for a specific site(s). In this case the site(s) has to be clearly indicated in all the communication material relating to the GreenLight Programme. More sites can be added to the company commitment and it is always possible to move from a site partnership to a corporate partnership or vice versa. Before, the partnership was at corporate level, covering all the eligible space owned or on long term leases (5 years or more) by the company joining the GreenLight Programme.

This adjustment was apparently not sufficient in UK. The Corporate response to GreenLight in the UK has been disappointing with only three Partners. According to the national Promoter, the most obvious feature of the failure of companies to respond to GreenLight was the low priority assigned to the initiative. Promotion of 'good' corporate public image was found to be of little concern, the Promoter said. Also, the Promoter claimed that the benefits of energy efficient lighting were a tired message in the UK (JRC 2002). To compound the difficulties of GreenLight in the UK, there was an established existing National Programme. This was the LightSwitch Programme, which had gained industry acceptance before GreenLight's launch. For all these reasons, the Promoter in UK concluded on the failure of GreenLight in his country.

In Germany, 6 pilot upgrades were completed and 7 signatures were registered. While up until now GreenLight used to rely mostly on a regional agency, promotion is now supported by 4 GreenLight Promoters, including the newly formed national energy agency.

The only countries with 10 or more Partners are: Italy(101), Belgium(35), Spain(25), France(20), Portugal(18), Austria (15), Norway(14), The Netherlands(13), Germany(10) and Greece(10).

In Sweden, GreenLight has been marketed since its inception without waiting for the completion of the first pilot case studies. Fifty companies were contacted by telephone and more than 10,000 people were reached though mail. The Promoter reported that it was far more efficient to first identify and call the right person in the company and then send a brochure. Sending a brochure to the company with no prior phone call turned out to be useless. The Promoter selected large, well-known companies that owned a lot of space (or used space on long term lease) and that were spread out geographically in Sweden. They also looked at the list of ISO 14001 authorised companies and selected some of those. Other companies were selected because of a good personal relation, such as companies they had worked with before on lighting issues. A workshop that featured fresh partners presenting their own arguments for signing received very positive reactions. It was also the opportunity for the attendees to get in touch with other professionals in the same field. They said that was also what they expected from GreenLight.

About the same number of companies were phoned and followed in Spain. GreenLight was presented in various national events. GreenLight received support from Spanish lighting business, twenty one Partners have been recruited. The 'green image' was felt to be the strongest argument to sell GreenLight to potential Partners.

In Norway, the solution which proved to be successful was to have potential Partners enrol first in a GreenLight pilot, and then investigate signing up for the corporate GreenLight commitment. By first getting companies to sign a relatively light Letter of Intent, the Norwegian Promoter achieved a vital starting point within the companies. Companies then felt obliged to thoroughly consider GreenLight.

Indeed, in general, companies have tended to adopt a "wait and see" attitude. In particular, companies lacking good energy management had no idea how the energy was used, how much could be saved, and how important lighting was for occupants. They wanted first to be convinced. The revision of the Partners guidelines, to allow partnership at the level of one site, should help overcome that barrier.

In Italy, the energy managers network and the Promoter's diligence were instrumental to enrol new Partners. The presentation of GreenLight at various seminars for energy managers resulted in several contacts and new partners. Electricians and facility managers knew their fields and easily saw the benefits of GreenLight. Energy Service Companies (ESCO) have proved also to be quite successful in promoting GreenLight to Italian municipalities. Italy was the most successful country due mainly to the excellent work by the Promoter

In general, whatever the country, reliable contact name within the organisation was of vital importance for success. A champion inside the company could play a decisive role in prompting the company to adopt energy-efficient lighting practices. Facility managers were often eager to obtain the benefits of GreenLight, especially those who had had previous experience with pilot energy-efficient lighting upgrades. GreenLight was an opportunity to raise their profile, get additional credit and extend their action to other premises. In some cases, GreenLight Promoters found it easier to speak to environmental or energy managers and have them convince top managers than the other way around.

The New IEE project

The goal of the New GreenLight project is to achieve at least 110 new partners committing to the GreenLight principles in the new EU member and EU candidate countries and over 20 GWh/year of savings at the end of the project. Each National Contact Point should also identify at least 3 endorsers every year.

These results will be achieved by the transfer of current GL know-how from the EU15 to the new member states and by a range of marketing activities. These include the production of guidelines for potential partners and supporters, printed brochure, a CD-rom and PPT presentation, updating of the programme's web-site, promotion leaflet, organisation of seminars and individual consultations, conference presentations, etc.

The main objective of the proposed action is to enlarge the geographical scope of the European GreenLight Programme, which is an explicit part of the Action Plan to Improve Energy Efficiency in the European Community.

In the short term the objective is to develop energy-efficient lighting in building area when these practices generate sufficient energy savings to represent profitable investments, and maintain or improve lighting quality.

In the long run, GreenLight is expected to contribute to significant positive environmental impact, but also to a more sustainable energy policy and enhanced security of supply, as well as to other benefits such as better working conditions and improved competitiveness. GreenLight can indeed help overcome some of the key market barriers associated with cost-effective investments in energy efficient lighting technologies and methods (not only) in the new EU member states.

Each GL National Contact Point (participant of this project) will undertake a series of efforts to have local companies signed up. An effort will also be made to identify appropriate Endorsers as well who will assist with identifying project partners.
In order to achieve this, a series of local seminars will be organised, combined with individual face-to-face meetings with the top-managers. Participants will present the GL programme at two major international conferences or workshops; to the redaction of a biannual newsletter highlighting success stories, new Partners, etc.; through the constitution of small GreenLight press dossier (prepared together with the JRC).

Participants will also answer all the GreenLight-related questions in their country and offer individual assistance to the GL partners and endorsers. They will also undertake a quick survey of national studies on lighting energy use and potential savings.

Conclusion

GreenLight is one of many new initiatives trying to create effective public private partnership to achieve societal and environmental benefits. GreenLight has proved to help its Partners save money and reduce pollution by increasing the energy efficiency of their lighting. GreenLight is changing the way organisations make decisions about energy-efficiency, elevating decision-making to senior corporate officials.

An increasing number of companies and public entities have experienced GreenLight 'win-win' opportunities and begun to view energy efficiency upgrades not as cost centres, but as profit centres. The number of Partners was multiplied by more than twelve fold between 2001 and end of 2005. Major players have joined the movement and several upgrades have got off the ground and flourished. These positive results prompted most national energy agencies to catalyse and spread further the programme implementation.

The objectives shared by the EC together with the energy agencies for 2006 are to closely follow-up and assist current Partners, to provide Partners with suitable recognition, and to use GreenLight success stories to convince peer companies to join. The main focus will in the New Members States and Candidate Countries, where there are currently no Partners, except one in Slovenia. In tangible terms, by end of 2006, the objectives are to increase and maintain a reporting rate of at least 80%, to pass the bar of four hundred registered Partners, and to double the current annual energy savings.

Given the success of the GreenLight programme the EC is now using same concept (i.e. cost effective efficiency improvements in buildings) to other building equipment and services (e.g. HVAC, office equipment, appliances) and to introduce the concept of energy management in the new European GreenBuilding programme (http://energyefficiency.jrc.cec.eu.int/greenbuilding%20programme.htm) (Agricola 2006).

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Techno-economic viability of a microtrigeneration system integrated in a low energy demand public building

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Abstract

The objective of this paper is to present the viability of a microtrigeneration system based on micro gas turbines or reciprocating engines, with a heat recovery system for heating and with an absorption chiller for cooling integrated in a low energy demand building. The building will host the headquarters of the Municipal Police of the city of Tarragona (Spain) including offices, meeting rooms, reception areas, etc in service the whole day. It has a constructed surface area of more than 4,000 m^2 and includes isolation measures above the required standards. The building uses natural ventilation and solar protection measures to reduce the energy demand and solar collectors for domestic hot water. The construction of the building will began in 2006.

In the work presented here, the building thermal demand in an hourly basis is calculated using a simulation model developed using the software TRNSYS. From a technical and economical point of view the best microtrigeneration alternative consist of a natural gas engine of 67 kW_e, a hot water driven single effect absorption chiller of 106 kW, a compression chiller of 50 kW (COP of 3,5) and a hot water storage system of 8 m^3. In this case the primary energy saving will be of 29 %, with a mitigation of dioxide carbon emissions of 35%, both compared to an equivalent conventional system (gas boiler and compression chillers) and to add to the energy saving due to the implemented architectural measures. The integration of a compression chiller in the selected trigeneration configuration helps to reduce the hot water storage volume and at the same time provides a back-up for cooling. An energy management system is introduced to guarantee the optimal cogeneration unit operation for those periods of low thermal energy demand.

1. Introduction and objectives

The use of trigeneration systems, despite their higher cost compared with conventional alternatives, usually has some benefits in terms of primary energy consumption and air pollutant emissions. The success of trigeneration systems implementation depends on energy demand profiles characterised by the type of application and the geographic location of the end user.

In the case of north European countries, one of the most important reasons of the low use of cogeneration systems is the fact that heat could be recovered during the wintertime only. In the other side, in Mediterranean countries the possibility to use the heat to produce cooling in summertime with absorption systems helps to equalise the net annual thermal energy demands. However in the field of residential and tertiary sector in some geographical areas the use of heat to produce cooling is not enough to equalise the energy demand to acceptable levels for the efficient operation of the system, because the use of cooling in summer is generally more intensive than heating requirements in winter. Moreover, this cooling is mainly provided in trigeneration systems with single effect absorption chillers, characterised by a relatively low COP that increase and unbalance the annual thermal demand.
For this reason, in opposition to north European countries in Mediterranean countries, in some cases the intensive use of cogeneration systems is carried out in the summer season. This fact is a benefit for the promotion of the use of cogeneration systems but can be a problem for the low thermal

demand in wintertime compared to summer time depending on the geographical location of the end user.

This problem can be faced using a trigeneration system with an appropriate energy management. On the one hand, thermal storage in summertime allows the use of smaller cogeneration units by storing the thermal energy to supplement the chiller capacity during high peak periods. In wintertime, that is when the thermal demand is lower, the storage systems can be used to maintain the cogeneration unit working over a minimum load to avoid low efficiency due to a excessively low partial load.

This solution, represented graphically in Figure 1, has been applied to the building that will host the headquarters of the Municipal Police in Tarragona (Spain) to solve the problem that represents the high variability of the thermal demand as will be shown later (section 4).

All results obtained with the different microtrigeneration alternatives analysed have been compared to that of a conventional system (section 5). The conventional system consists of a boiler unit and a compression chiller to produce the required heating and cooling and buying the required electricity from the grid. There is no detailed information about the building electrical demand. For the different cogeneration alternatives analysed in this study, all the produced electrical energy is sold to the public grid.

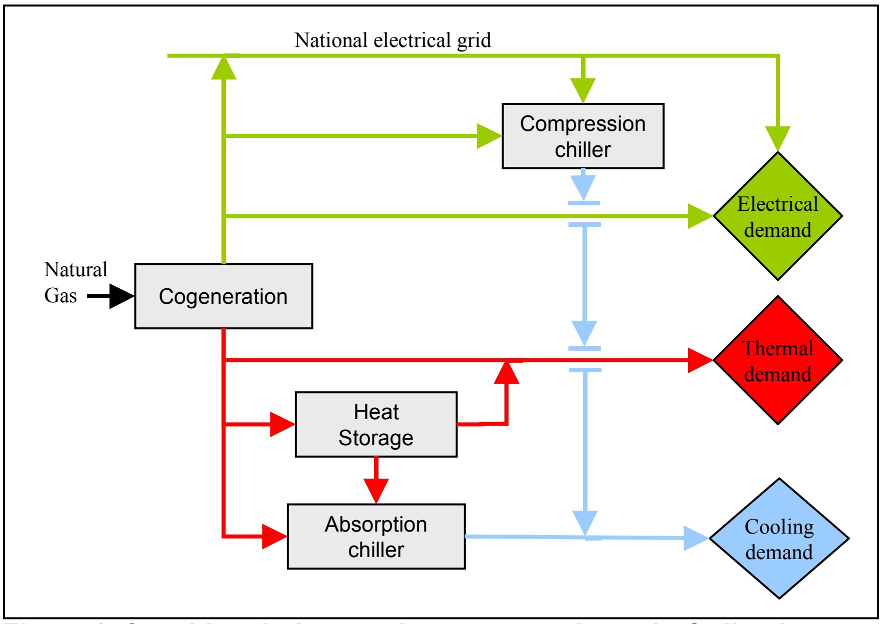

Figure 1. Considered trigeneration system scheme including heat storage.

2. Description of the building

The new building for the headquarters of the Municipal police (Figure 2) will be built in an area of future urban expansion. The building is located in an area of trapezoidal form of 4306 m^2 oriented East-West.

The building is organised in two parallel bands differentiated by their use, that gives to the building its characteristic image. One of the bands, with three floors (8 x 63.5 m) includes the offices and the living areas specific for headquarters. The other one (15.5 x 56 m) located in the North part of the lot, includes the rest of the services: meeting rooms, the lobby of access, the zone of attention to the public, etc. In the underground plant hosts the car parking and areas for storage. Two vertical nuclei guarantee the connection between the two bands, maintaining the separation between the public and private areas. In the South facade of the office band a cable structure allows the growth of climbing plants that conform a new green facade of the building.

The installation will have an irrigation system of low consumption and rainwater accumulation, and a system to reuse grey waters for the toilets with mechanisms to reduce water consumption. The two main facades are oriented to south and north direction with wood and climbing plants for solar protection in the South facade. The isolation is increased a 200 – 300 % with respect to the normative standard relative to opaque facades. In this building a double glass window and low emission is used.

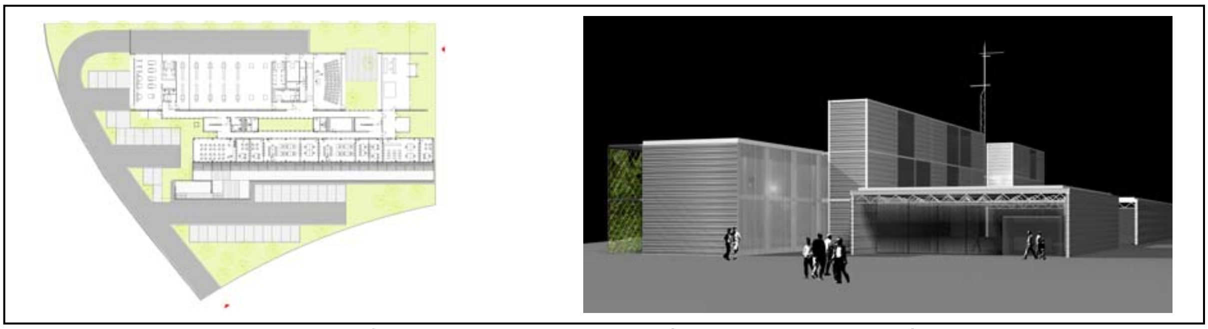

Figure 2. The headquarters of the Municipal Police: a) Building layout, b) Main entrance.

3. Modelling of the building thermal loads

The thermal loads of the building were calculated with the modular solver TRNSYS-version 16, a well-suited computer program for thermal systems simulation. In TRNSYS, the model of a system is built by linking its constituent subsystems, usually defined as high level entities (building, water storage, controller, radiation processor, etc.). These links, representing control signals or directional energy and mass exchanges between subsystems, are solved by the program at each time step.

The TRNSYS model for the studied building is shown in figure 3. The main component is the standard multizone building model TYPE56, which is surrounded by other components that impose boundary conditions to it:

- TYPES 701c and 703c are three dimensional ground conduction models from the TESS libraries [1]. These units calculate the outside surface temperature of the walls in contact with the ground.
- The rest of the components on the left side of the deck process the meteorological conditions that TYPE9 reads from a text file. TYPE16 is the radiation processor that calculates the components of solar radiation (beam and diffuse) for the different orientations of the building facades, TYPEs 810 and 68 are shading processors that modify the radiation terms due to the presence of window overhangs and remote obstacles respectively, TYPE33 is the psychometric properties calculator, and TYPE69 is the sky temperature calculator.

In the following points the most important steps in the model formulation are briefly described:

- ZONING: The first step is to define the thermal zones by grouping together those spaces in the building with similar gains (conduction, solar, lighting, equipment and people) and set points, or under the action of the same controller when the configuration of the air conditioning system is already known. In the present case the building has been split into twenty four zones distributed over four floors.
- WALLS AND WINDOWS: Once the different zones have been defined, the next step is to define the thermal properties of the walls and the optical properties of the windows, that are included in each zone. With regard to the later, the angular behaviour of the windows was calculated with the third party program WIS [2], whose database contains detailed information about the products of the corresponding Spanish manufacturer.
- CASUAL GAINS: Internal gains and occupancy schedules are usually difficult to define because of the large uncertainty related to the use of the zones. The assumed profile is for an extended office usage (from 7 to 19 h on working days) in most of the zones and twenty four

hour use in some special rooms (computers, traffic lights control,…). Nominal values of internal gains are mainly provided by ASHRAE [3].

- EQUIPMENT: Conditioned zones are considered to be supplied by ideal convective equipment, which adds the precise quantity of heat flux to maintain a preset air temperature between 22ºC and 24ºC at every time step (1 hour). Unconditioned zones (garage, stairs, etc.) are modelled in free floating temperature mode, so as to improve the calculation of heat transfer fluxes between internal partitions simultaneous thermal inversion is allowed.
- WEATHER CONDITIONS: Several sources of meteorological data for Spain are currently available: Meteonorm, Trnsclima Calener, etc. The Trnsclima database compatible with the format required by Trnsys type 89 has been used. This software provides three different meteorological years for every city: typical, extreme cold and cloudy, extreme hot and sunny. It has been used the meteorological data of Vandellós; climatically the closest place to Tarragona where the building is located and available in the database.
- RADIATION CALCULATIONS: The weather file provides the total horizontal radiation and the beam normal radiation. The radiation processor calculates the components (beam and diffuse) of the radiation over each external orientation of the building by using the Reindl model (others models are provided). The radiation over the windows is modified to take into account the presence of overhangs and obstructions.
- GROUND CONDUCTION: The ground models are purely conductive. Due to the large time constant of the ground, the simulation takes several years to converge (due to time constraints, we have simulated three years for every case).

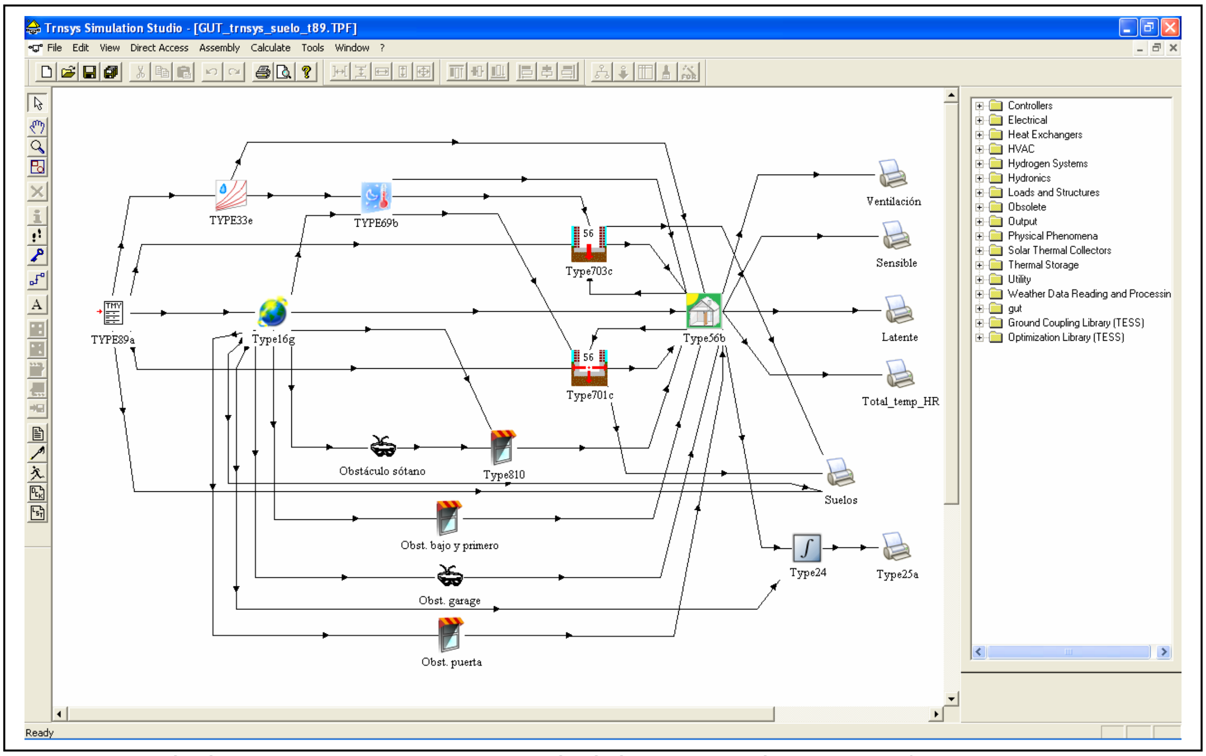

Figure 3. TRNSYS model as seen in the TRNSYS Simulation Studio interface

4. Building thermal loads

The hourly power demand of heat, cold and total heat of the building for a whole year is shown in Figure 4 and was obtained with the simulation results of the building model presented in section 3. Total heat refers to the demand of heat for heating plus the heat necessary to produce cooling with a single effect water/LiBr absorption units (COP = 0.7).
As shown in figure 4, during summer months the demand of heat is higher than the rest of the year due to the use of heat to produce cooling. The cogeneration system has to be designed to supply the

high thermal demand expected in summer to produce cooling and at the same time be flexible enough to reduce their load the rest of the year. This has been addressed using a thermal storage system.

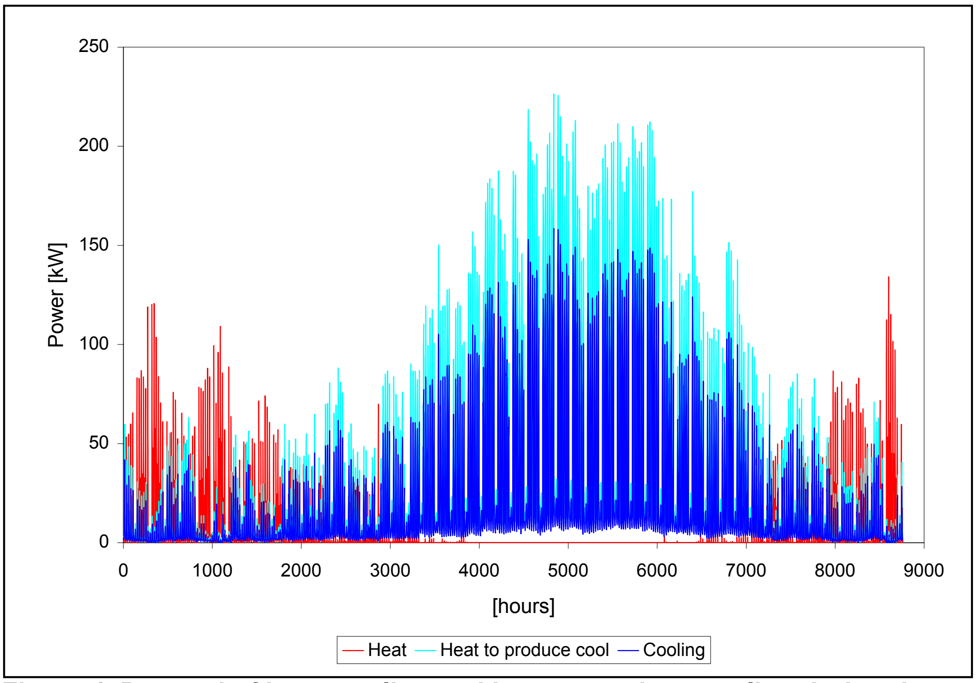

Figure 4. Demand of heat, cooling and heat to produce cooling during the year

The results of the building model show that the demand for heating is quite constant throughout the year excluding the hotter months (from May to September) where the demand for heating is almost zero. On the other hand there is a demand for cooling almost throughout the year, of course with a maximum load during summertime. The heat required to produce cooling is almost twice the heat required for heating in winter. The demand profile for different days in each month has been represented to analyse its characteristics. Figure 5 represents an example of a cold day (January 15th) and a hot day (July 15th).

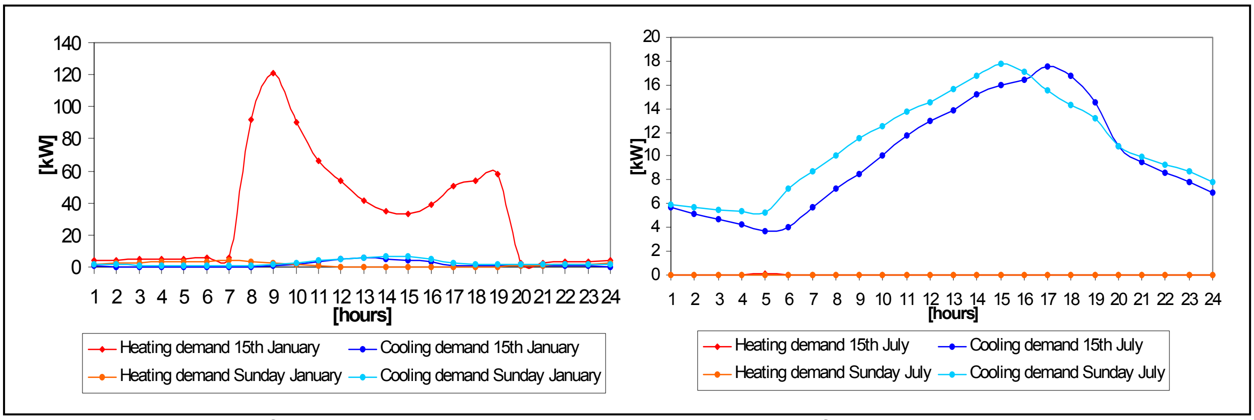

Figure 5. Demands of heat, cooling and heat to produce cooling for hot and cool day

There is a great difference in thermal demand between working days and weekend days because the police station follows a working day profile and the offices are closed on Sunday. The demand follows approximately the same pattern every day. For heating, the peak hour is usually at about 9 a.m. and for refrigeration, it is between 2 and 4 p.m. So the peak in thermal demand will change depending on the predominant type of service (heating and cooling). The time period for the higher demand of heating as well as cooling is between 7 a.m. and 8 p.m.

5. Energy supply alternatives

The most accepted criteria to design a cogeneration system is to cover the total heating demand of the user, in our case the building so the waste heat produced by the electric generator is converted completely in useful heat. Figure 5 shows the aggregated heat demand curve for the building. This curve represents the number of hours (axis x) that the total heating demand will be equal or higher than a given power demand (axis y). To calculate the thermal input required for the absorption chillers in each trigeneration alternative a hot water driver single effect water/LiBr chiller (COP=0.7) is considered. It is not possible to use a more efficient double effect chiller because for the small size of the cogeneration units considered (less than 70 kW_e) there is no commercial chiller available that could be driven directly by exhaust gas of this cogeneration system.
Based on figure 5, four alternatives have been considered as electric generator unit for the cogeneration system (Table 1): two micro gas turbines (MGT) (Capstone C30 of 30 kW_e and C60 of 60 kW_e, [4]) and two gas engines (EQTEC EG48 of 48 kW_e and EG67 of 67 kW_e [5]). The main characteristics of these cogeneration units are given in table 2.
By means of the graph in figure 6 the different degree of thermal demand coverage can be determined for each trigeneration alternative. For example, a microturbine of 60 kWe produces a thermal power at nominal conditions and full load of 110 kW_t (black line), thus it produces a 87 % of the total thermal demand, and the remaining 13 % will have to be covered with auxiliary equipment or thermal storage systems. With a microturbine of 30 kW_e (green line) the 73 % of thermal demand will be covered and the remaining 27 % by other means. In the case of gas engines, with the EQTEC EG48 of 79 kW_t (blue line) and EQTEC EG67 of 109 kW_t (orange line), an 80 % and 86.7 % of thermal demand will be covered, respectively, by the trigeneration system. The remaining 20 % and 13.3 %, respectively, by other means.

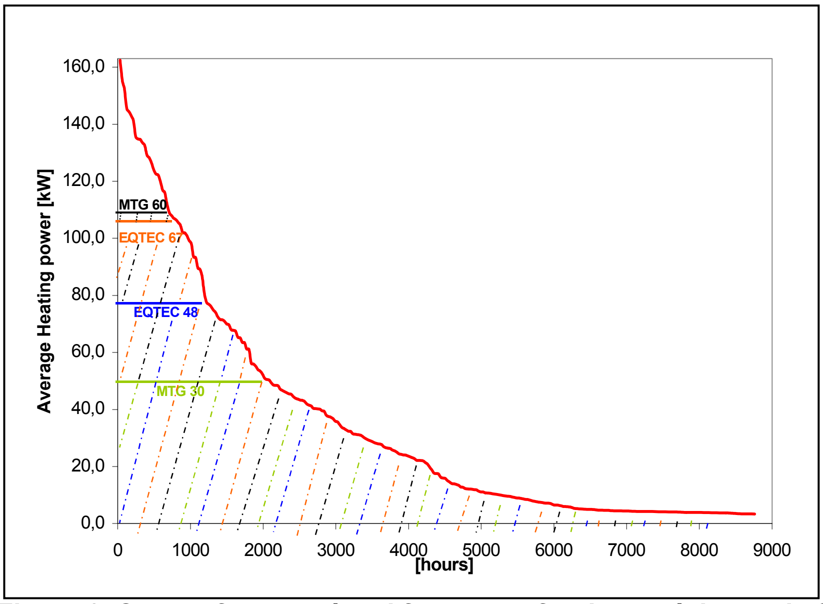

Figure 6. Curve of accumulated frequency for the total demand of thermal energy.

Table 1. Electric generator alternatives considered.

Equipment		C30	C60	EG48	EG067
Type		MGT	MGT	Gas Engine	Gas Engine
Cost	[€]	44871	73929	80686	90916
Electrical power	[kW]	30	60	48	67
Thermal power (120 °C)	[kW]	55	110	79	109
Electrical efficiency	[%]	26	28	32,5	32,8
Thermal efficiency	[%]	49	52	53,4	53,9
Total efficiency	[%]	75	80	85,9	86,8

The monthly energy demand of the building is shown in Table 2. As mentioned before there is a great difference in thermal demand between working days and Sunday. So it was considered to analyse these two demand profiles together and separately to evaluate the effect on the demand profile. Table 3 shows the demand during low activity days (Sundays) for each month.

Table 2. Monthly energy demand throughout the year.

Month	Days	Heating Demand [kWh]	Refrigeration Demand [kWh]	Thermal Energy for Cooling [kWh]	Thermal Energy Total [kWh]
January	31	10269	4710	6728	16997
February	28	8165	3118	4454	12619
March	31	5028	4845	6921	11949
April	30	2061	7517	10738	12799
May	31	562	15287	21839	22401
June	30	26	25742	36774	36800
July	31	0	36919	52741	52741
August	31	0	36944	52777	52777
September	30	17	26283	37547	37564
October	31	517	16742	23918	24435
November	30	4380	7390	10557	14936
December	31	9480	4049	5785	15265

Table 3. Monthly energy demand on Sundays throughout the year.

Month	Days	Heating Demand [kWh]	Refrigeration Demand [kWh]	Thermal Energy for Cooling [kWh]	Thermal Energy Total [kWh]
January	4	131	259	370	501
February	4	158	206	294	452
March	4	82	355	507	589
April	5	46	506	723	770
May	4	7	661	944	951
June	4	2	901	1287	1289
July	5	0	2206	3152	3152
August	4	0	1281	1830	1830
September	5	0	1004	1435	1435
October	4	2	889	1270	1273
November	4	36	436	622	659
December	5	91	260	371	462

The complete energy and economic balance for each alternative based on the data of Tables 2 and 3 has been calculated and evaluated under different hypothesis. The results are shown in Table 5. For each microtrigeneration alternative it has been considered two cases:

- using the load of the complete year (row *Every day* in Table 5)
- using the load without taking into account the load for Sundays (row *Monday-Saturday* in Table 5*)* where the trigeneration system will be shut off.

The energy demand profiles in a building are characterised by a high load variation during the same day. Thus it is not clearly justified to use the nominal thermal and electric efficiency of the cogeneration system to calculate the energy and economic balance of the energy supply system. To evaluate the influence of the variable efficiency with the system load in the energy and economic balance, within the two cases previously considered (working the whole week or just from Monday to Saturday) two new cases are considered:

- use nominal efficiencies for each cogeneration system (fixed values independent of the load)
- use variable efficiency for each cogeneration system as a function of the load. In these cases the efficiencies considered are the average efficiency for each month.

The data used to calculate the energy and economic balance for each alternative additionally to the capital cost data for each cogeneration system already given in Table 2 is the following:

✓ Cost of the Natural Gas: 0.018 €/kWh
✓ Cost of electricity: 0.085 €/kWh
✓ Capital cost for the absorption chiller: 126 €/kWh
✓ Capital cost for the boiler (conventional system): 5000 €
✓ Capital cost for the compression chiller (conventional system): 25600 €

The cost saving column in Table 5 is calculated as the difference between the operation cost of the conventional system and the cogeneration system.

Table 5. Results obtained for each microtrigeneration alternative

Equipment	Performance	Capital Cost [€]	Cost Saving [€]	Payback [Years]	Primary Energy Saving [%]	CO_2 Emissions Saving [%]
C60						
Every day	μ_t=0.52; μ_e=0.28	86403	9098	7	15%	28%
	μ_e, μ_t(load)	86403	6123	11	1%	18%
Monday-Saturday	μ_t=0.52; μ_e=0.28	86403	8743	7.6	15%	28%
	μ_e, μ_t(load)	86403	6272	11	4%	20%
C30						
Every day	μ_t=0.49; μ_e=0.26	87945	7407	7.7	8%	22%
	μ_e, μ_t(load)	87945	6728	9.1	-1%	14%
Monday-Saturday	μ_t=0.49; μ_e=0.26	87945	6699	8.6	8%	22%
	μ_e, μ_t(load)	87945	5760	10	0%	15%
EG48						
Every day	μ_τ=0.534; μ_e=0.325	93160	11024	5.7	23%	34%
	μ_e, μ_t(load)	93160	8825	7	26%	34%
Monday-Saturday	μ_τ=0.534; μ_e=0.325	93160	10594	6	24%	34%
	μ_e, μ_t(load)	93160	8837	7	16%	29%
EG67						
Every day	μ_t=0.539; μ_e=0.328	103390	11119	6.5	24%	35%
	μ_e, μ_t(load)	103390	7619	10	29%	35%
Monday-Saturday	μ_t=0.539; μ_e=0.328	103390	10685	6.8	24%	35%
	μ_e, μ_t(load)	103390	7025	10	8%	23%

The microturbine of 30 kW_e and the gas engine of 48 kW_e do not cover the high thermal energy demand during summer months. Also for these two cogeneration units a thermal storage system will not be feasible due to its enormous dimensions. It is clearly shown in Figure 7 where it is represented the calculated volume and cost for a hot water thermal storage system as a function of the thermal power provided by a given cogeneration system. In this figure the unitary storage cost has been obtained from the available bibliography [6]. Additionally the primary energy saving is small or even zero in some cases for the option using a microturbine of 30 kW_e. The option using a gas engine of 48 kW_e produces a considerable saving in emissions of carbon dioxide and an affordable payback, but due to the large storage system that would be necessary this option is also discarded.
For the microtrigeneration options using a microturbine of 60 kW_e and a gas engine of 67 kW_e the payback is quite high but it will be reduced if the potential subsidies that could be obtained for a system of such characteristics were considered. In addition in these two cases the saving in primary energy and emissions of carbon dioxide is considerable. For this reason, in the following section it is analysed in detailed the design of an optimal storage system for these two cases to guarantee the supply of the required thermal demand during peak demand periods. Both storage systems are considered as the same because the thermal power provided by the microturbine and the gas engine is the same.

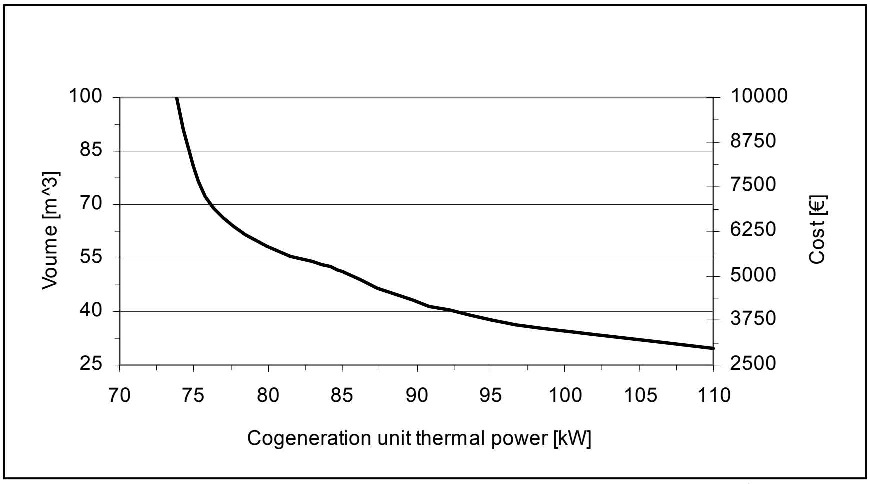

Figure 7. Required hot water storage volume and cost as a function of the cogeneration thermal power

6. Analysis of the energy management system

The volume required for the hot water storage can be considerably reduced adding an auxiliary compression chiller. In this case the cooling load for the absorption chiller is lower and subsequently the thermal load for the cogeneration system is also reduced. At the same time the use of an auxiliary chiller introduces a certain degree of back-up cooling to the building energy supply system.
Different compression chiller sizes have been studied considering for all of them a COP of 3.5. Next the results for the selected 50 kW of cooling unit are presented. It has been found that the use of this chiller reduces the storage volume four times. The selection of compression units is made analysing the operational performance of the whole system. Figures 8 and 9 show some of the operational characteristics that have been taken into account to determine the most suitable compressions chiller unit. As presented in figure 8, the number of running hours for the auxiliary compression chiller is lower than 900 hours per year. Its operation time is shown in figure 9.

Once the system configuration is selected and sized (electric generator, absorption chiller, hot water thermal storage and auxiliary compression chiller), it is necessary to evaluate some operational restrictions to determine the most appropriate operation mode for the cogeneration unit in order to avoid low efficiency. The objective is to enhance the global performance compared to conventional alternatives. In summer time (figure 10) the cogeneration thermal power is exceeded almost all time and the cogeneration unit works at its maximum capacity, 110 kW_t as it is shown in Figure 10. The compression chiller is also in operation many times at its maximum cooling capacity (50 kW) during peak loads and the hot water storage (blue line, Figure 10) is used as required to cover completely the heating demand.

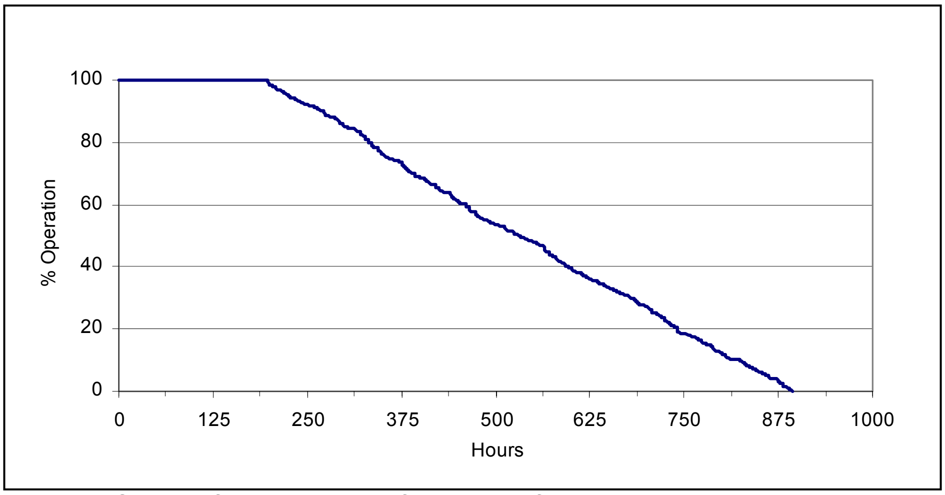

Figure 8. Curve of accumulated frequency for compressor chiller operation.

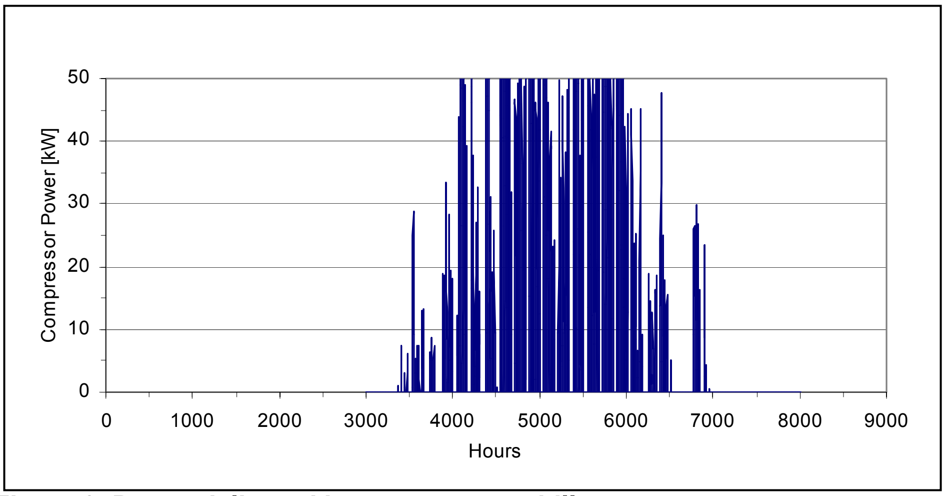

Figure 9. Power delivered by compressor chiller

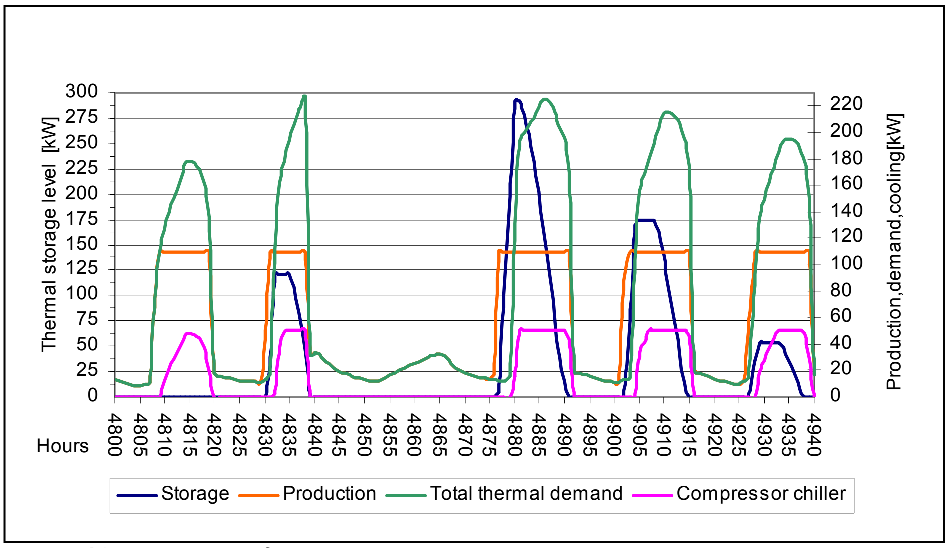

Figure 10. Example of microtrigeneration operating conditions during a period of high thermal demand.

In contrast, in wintertime there is a lower thermal demand and the cogeneration system works many times at very low partial load. There are two operational alternatives to avoid low efficiency: in the operational mode that we call "Demand" the cogeneration unit works following the total thermal demand at any time, without taking care if sometimes its efficiency is too low due to excessively low partial load. In the operation mode that we call "Constant load" the cogeneration unit only works during high demand peak periods at a medium load to help to supply the required thermal energy and to store enough energy in the hot water storage system to supply the demanded energy during low demand periods when the cogeneration unit is turned off. The system operation in summer time should be in "Demand" mode because the cogeneration unit capacity is exceeded almost all time, but in wintertime the thermal storage system is used to favour a higher performance of the cogeneration unit.

An example of constant load operation mode is shown in Figure 11. In the time period shown in this figure the cogeneration unit is running at 55 kW_t (50% of the nominal load) with some peaks at 75%. When it is shut off the storage system takes over the whole thermal demand. In this way when the cogeneration system is running it can do it at its higher load and thus at its maximum efficiency.

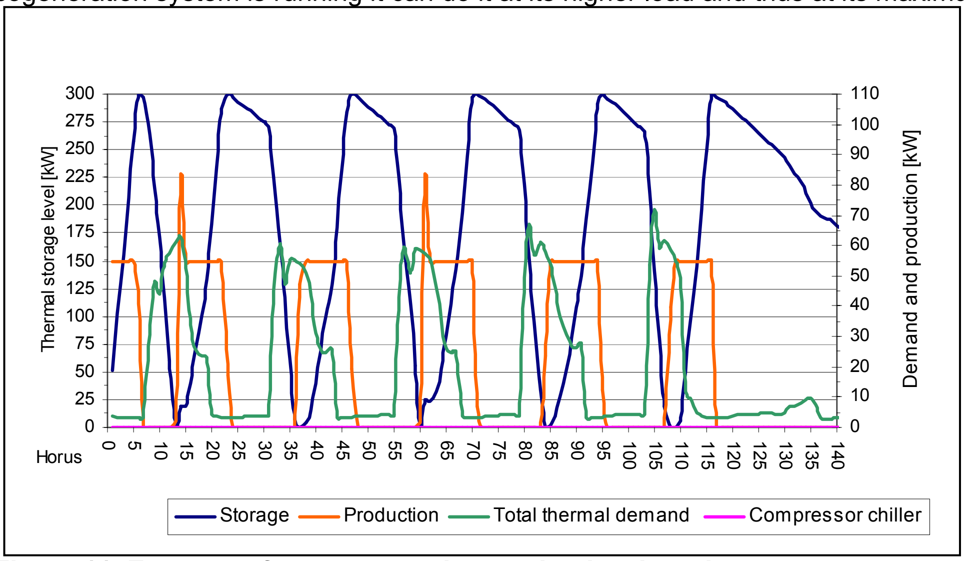

Figure 11. Example of constant load operation in wintertime.

The cogeneration unit will be working always during high demand periods (that is, daily labour hours), because in this way it helps to maintain a higher medium charge level, and the electricity is produced when it is more valuable. The electricity cost is usually more expensive in the period between 9 a.m. and 2 p.m. This is an important point that has to be considered to determine when it's the best period to maintain the cogeneration unit on.

The results of the study performed with the two best alternatives (C60 and EG067) selected in the previous section (section 5) are presented in Table 6. The energy and economic cost balances have been calculated for each alternative using the two operational modes mentioned above (demand mode and constant load mode). It is important to notice in this table the reduction in Natural Gas consumption with the cogeneration unit working at constant load because the unit works at low load or what is the same, at low efficiency, less hours than in the Demand following mode.

The payback period is always considered in comparison with the conventional case (boiler for heating, electricity from the grid and cooling using a compression chiller) and without considering any kind of subsidy for the use of more efficient and innovative systems for energy production. It is significant the difference between the microturbine unit and the gas engine when they are working in "Demand" mode with respect to the "constant load" mode. This fact is due to the higher impact of the partial load on the microturbine efficiency according to the public data provided by the manufacturers.

As shown in Table 6 the gas engine performs economically better that the microturbine. The integration of a 50 kW compression chiller to reduce the thermal storage volume is preferred. Although from the economical point of view the use of a 30 kW compression chiller is slightly better the required space for thermal storage is considerably lower and better used during constant load operation with a 50 kW chiller.

Table 6. Results obtained equipment of cogeneration

System	Operational mode	Electrical Consumption [kWh/year]	Natural gas Consumption [MWh/year]	Benefits [€/year]	Capital Investment [k€]	Payback vs. conventional case	On line time [hours]	Off line time [hours]
(1)	Demand	-	694	3.778	118,7	9,6	-	-
(1)	Constant load	-	659	4.411	118,7	9,0	11	17
(2)	Demand	5.783	645	2.657	118,4	10,9	-	-
(2)	Constant load	5.783	603	3.426	118,4	9,9	11	16
(3)	Demand	7.668	629	2.291	117,5	11,3	-	-
(3)	Constant load	7.668	587	3.061	117,5	10,3	11	16
(4)	Demand	-	758	783	112,0	13,2	-	-
(4)	Constant load	-	698	2.012	112,0	11,0	11	17
(5)	Demand	5.783	713	-120	111,7	15,3	-	-
(5)	Constant load	5.783	609	1.787	111,7	11,3	11	16
(6)	Demand	7.668	697	-429	110,8	16,1	-	-
(6)	Constant load	7.668	615	1.060	110,8	12,4	11	16

(1): EG067
(2): EG067 Engine + 30kW compression chiller
(3): EG067 Engine + 50kW compression chiller
(4): C60 Microturbine
(5): C60 Microturbine + 30kW compression chiller
(6): C60 Microturbine + 50kW compression chiller

7. Conclusions

It has been proposed a microtrigeneration system to supply electricity, heating and cooling to a low energy demand public building. For this building the smaller cogeneration units (microturbine of 30 kW_e and a gas engine of 48 kW_e) can have some problems to supply all the thermal energy required in summertime to produce heat for the absorption chiller. So it would be necessary to use a very large storage system or to use of big auxiliary compression chiller. The small size of these units in comparison with the existing energy demand in some periods of the year will make them unsuitable from the environmental and economical point of view with respect to a conventional system.

For the microtrigeneration systems based on a microturbine of 60 kW_e and a gas engine of 67 kW_e, the integration of a compression chiller helps to reduce the hot water storage volume and at the same time provides a back-up for cooling in case of a cogeneration or absorption chiller failure.

The recommended microtrigeneration system consist of a natural gas engine of 67 kW_e, a hot water driven single effect absorption chiller of 106 kW available in the market, a compression chiller of 50 kW (COP of 3,5) and a hot water storage system of 8 m^3.

The 67 kW_e engine has a payback period lower than the 60 kW_e microturbine. For the gas engine option with a consumption of 587 MWh/y it will produce 168 MWh/y of electricity and 273 MWh/y of useful heat. In this case the primary energy saving will be of 29 %, with a mitigation of dioxide carbon emissions of 35%, both compared to an equivalent conventional system (gas boiler and compression chillers) and to add to the energy saving due to the introduced architectural measures.

The constant operation mode in wintertime with the help of the storage system is recommended to maintain the cogeneration system working at a minimum load to guarantee a minimum efficiency in opposition to the operation mode in which the cogeneration unit follows the thermal demand at any time. This constant load operation mode produces lower natural gas consumption thanks to its higher average efficiency.

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building
performance
congress

Solar Cooling Systems based on Parabolic Trough Collector PTC 1800 combined with Double Effect Absorption Chillers

A. Lokurlu, G. Müller

SOLITEM GmbH

Abstract
The worldwide rapidly growing energy demand, e.g. for cooling and process steam generation, and the boundary conditions of the existing fossil energy supply structures are leading to an increasing lack of fossil energy carriers and growing greenhouse gas emissions, which pollute the ecosystem. With the efficient utilisation of solar energy by parabolic trough collectors for heating, cooling and process steam generation, the demand of resources and the emission of climate depending harmful substances will be reduced. Besides, the share of fossil energy sources in the energy supply is diminished, and therewith the increasing costs of the receding fossil resources.
On three locations, Parabolic Trough Collector PTC 1800 systems have been installed. Two systems deliver heat for cooling with double effect absorption chillers as well as steam for the laundry of the hotel, and one system offers steam for industrial application.
Each system has at least two operation modes. These modes are designed to replace high fossil fuel or electricity costs with available free solar power. The operation modes are also depending on main energy consumers like laundry or air conditioning in hotels. So one operation mode replaces electricity driven compression chillers with solar driven double effect absorption chillers during high tariff times in summer, or it replaces expensive LPG for heating of existing boilers with solar generated steam. Another operation mode uses parabolic trough collectors during winter for heating of swimming pools, buildings or domestic water.
SOLITEM is the only supplier of efficient solar high temperature technology for buildings and factories worldwide. The system uses specially developed parabolic trough collectors to generate temperatures of up to 250 °C. These collectors open the market for highly efficient solar cooling with double effect absorption chillers. This is one of the most important technical solutions of the 21st century, and particularly applicable for the needs of hotels, hospitals and factories.
For its development, SOLITEM is the proud recipient of the internationally renowned Energy Globe Award 2004, the R.I.O. Innovation Award 2004, the Global 100 Eco-Tech Award 2005, the European Solar Prize 2005 and the World of Wonders Prize 2005.

Introduction
The sun is the ultimate energy source. Its energy surpasses the world's primary energy demand a ten thousand fold. SOLITEM's high goal is to optimise the use of this enormous energy potential, as it will take the largest share in the future energy mix.
Solar energy is environmentally friendly. It is practically unlimited and enables energy generation without CO_2 emissions. Despite the rising prices for fossil energy sources, solar energy will always be for free and is decentralised available.
In the Sun Belt Countries, nearly all public buildings like hotels and hospitals need air conditioning during the summer time. For this purpose, there is a great demand for electricity since most of today's air conditioning systems are based on electricity powered compression cooling systems. Due to the fact that the solar radiation is simultaneous with the cooling demand, it is expected that absorption cooling systems can be operated more economically compared to the existing conventional cooling systems.
The SOLITEM Group as a young and innovative company develops and installs absorption cooling systems operated with its proprietary developed parabolic trough collectors (SOLITEM PTC), which not only reduce the high electricity demand and costs for cooling, but also show a CO_2 emission free supply of the buildings.

SOLITEM Solar Cooling Systems based on SOLITEM Parabolic Trough Collector PTC 1800
combined with Double Effect Absorption Chillers

The Subject of SOLITEM's development is an integrated energy supply system based on parabolic trough collectors which are combined with a double effect absorption chiller connected with an existing cooling, steam and hot-water system for summer application and a warm water system for winter application e.g. swimming pool heating etc.
At the "Iberotel Sarigerme Park" of the TUI group in Dalaman/Turkey, the first SOLITEM solar cooling system was installed and has been operated successfully since winter 2003/2004. In the project development phase, the components had to be optimised in terms of size to get the optimal design by means of energy saving and investment.
Since then, another solar cooling system has been installed in Turkey, and at present we are installing some other systems in different countries with the aim of supplying air conditioning and steam for summer applications, as well as warm water for winter applications in hotels, hospitals and industrial facilities.

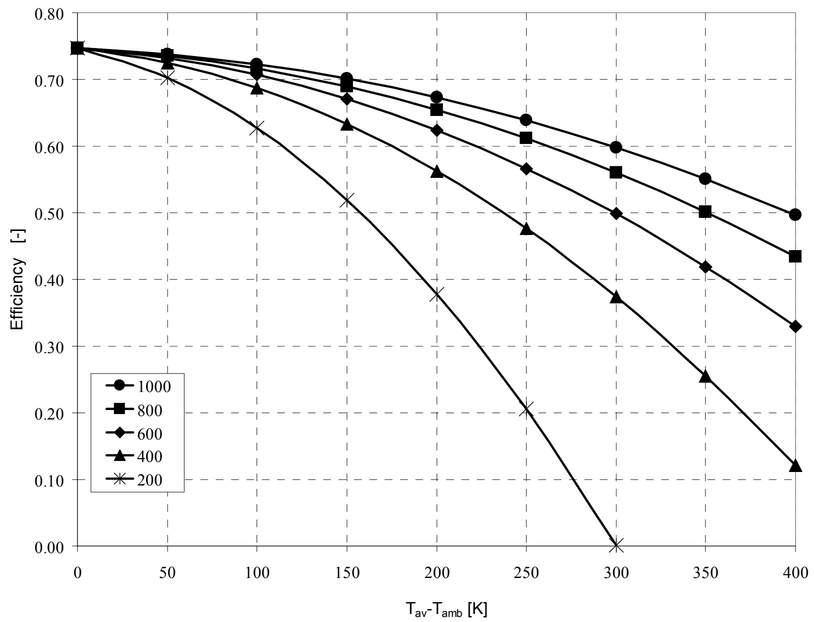
General explanations

Conventional solar systems

The biggest problem of flat plate and evacuated tube collectors is their low outlet temperature and connected with this their efficiency at high temperatures that prevents them from being efficiently used for air conditioning due to a COP (Coefficient of Performance) of approx. 0.4 to 0.5 by small sized applications. In order to satisfy a certain demand, a larger collector area is needed. But at many locations, like hotels, especially on roofs of buildings, space is limited. As a result, the application range of conventional solar systems is also limited.

The PARABOLIC TROUGH COLLECTORS of SOLITEM (PTC)

To overcome these problems and to widen the applications range for solar energy, SOLITEM developed two different sized Parabolic Trough Collectors (PTC): The SOLITEM PTC 1800 for large applications as well as the small sized PTC 1100 for residential buildings. Both collectors have a supply temperature of 200 °C to 250 °C and are capable for roof mounting. The following standardised curve shows the efficiency versus DT/G of the SOLITEM PTC 1100 for different solar radiation and temperature values.



Effiency curve of PTC 1100 for different solar radiation and temperature values [Source: Solar Institute Juelich]

SOLAR COOLING APPLICATIONS

A very promising application of the system is solar cooling. The high temperature level of the parabolic trough collectors allows the operation of a highly efficient two stage absorption chiller. With a performance almost three times higher than the one of a single stage absorption chiller (COP up to 1.5), the technology of solar cooling becomes much more attractive. For the first time, there is a real alternative to conventional air conditioning systems.

FIELDS OF APPLICATION

In contrast to flat plate and vacuum tube collectors the solar high temperature range is opened through the SOLITEM PTC. The results of this are many additional application fields for solar energy use. These application fields are incorporate solar cooling and air conditioning, process heat supply for hotels and hospitals (laundries, kitchens, sterilisers) as well as solar energy supply of production and storage facilities with process steam demand.

Solar process steam generation, cooling and heating are the already mentioned basic applications of the system. But this is only the beginning: process steam with a pressure of 4 to 8 bar is a highly valuable energy source and can be used for numerous other applications:

- Electricity Generation
- Desalination
- Combined Heat, Cooling and Power (CHCP)
- Chemical Industry
- Food Industry
- Textile Industry

The system can provide cooling, heating and process steam at the same time. To make it even more profitable, it is operated bivalent and also tariff depending. The control unit is adjusted to the customers' individual needs and thus helps saving as much energy costs as possible.

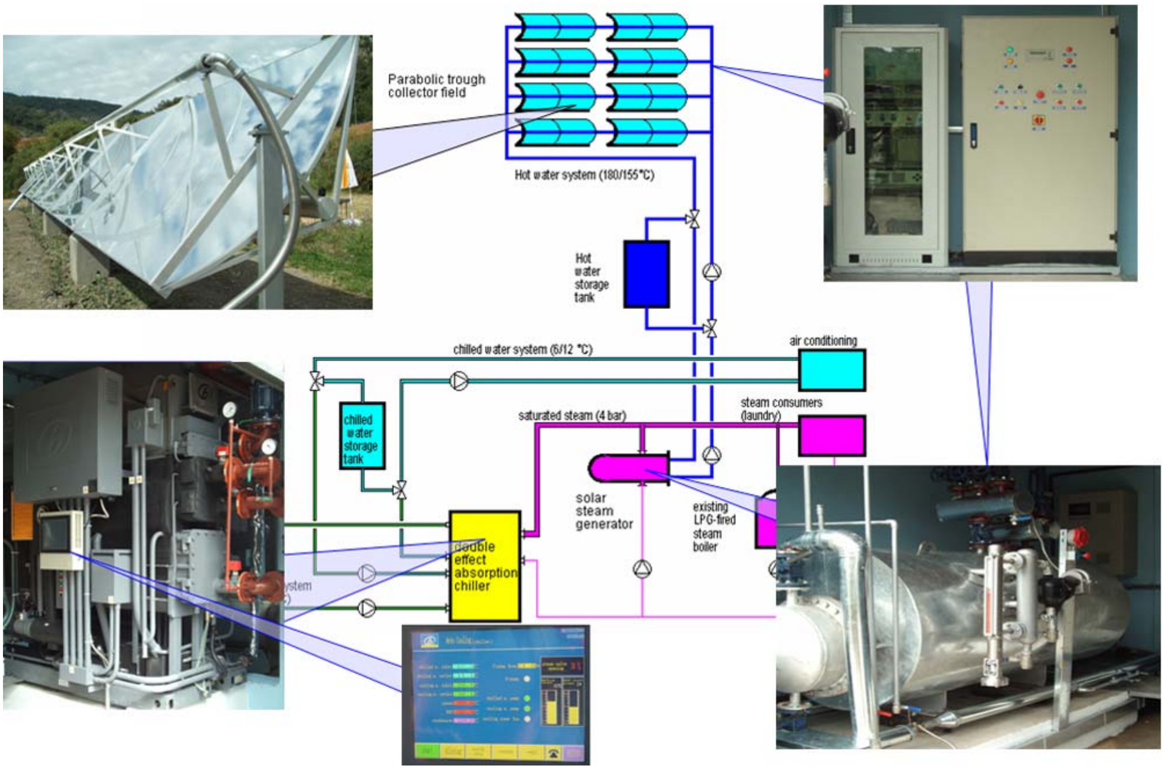
The solar combined heat, cooling and power is a crucial economical and ecological, highly efficient application. In the first step of the application, solar energy is used for electricity generation and in the second step, the heat supplied by the power process is used for generating chilled water and for supplying heat consumers. This example shows a clear advantage of parabolic trough systems in comparison to solar electricity generation with photovoltaic systems.

A model application for an integrated energy supply system

An example for an integrated supply system developed by SOLITEM is the “Iberotel Sarigerme Park” in Dalaman/Turkey, which is equipped with an air conditioning system that is operated with a double effect absorption chiller.

As one can see in the schematic diagram below, the main principle of the SOLITEM system is that the collector field delivers high temperature heat at the level of 200 °C to 250 °C in the first cycle. In a steam generator that is placed between the first and the second cycle of the process, saturated steam is produced at 4 bar, which can be used for the air conditioning in the double effect absorption chiller on the one hand and, on the other hand, for the steam supply of the laundry of the hotel. For different seasons, e.g. for summer and winter applications, an improved system configuration has also been developed for this location to maximize the economic use of solar energy. An important aspect of the use of the SOLITEM system is that this system is not limited to only supplying buildings with air conditioning and/or laundries and kitchens with steam during summer time: it can also be used for the heating of buildings or swimming pools in transition periods so that profitability increases significantly.

SOLITEM Solar Cooling Systems based on SOLITEM Parabolic Trough Collector PTC 1800
combined with Double Effect Absorption Chillers



Schematic diagram of the SOLITEM System at the Iberotel Sarigerme Park, Turkey

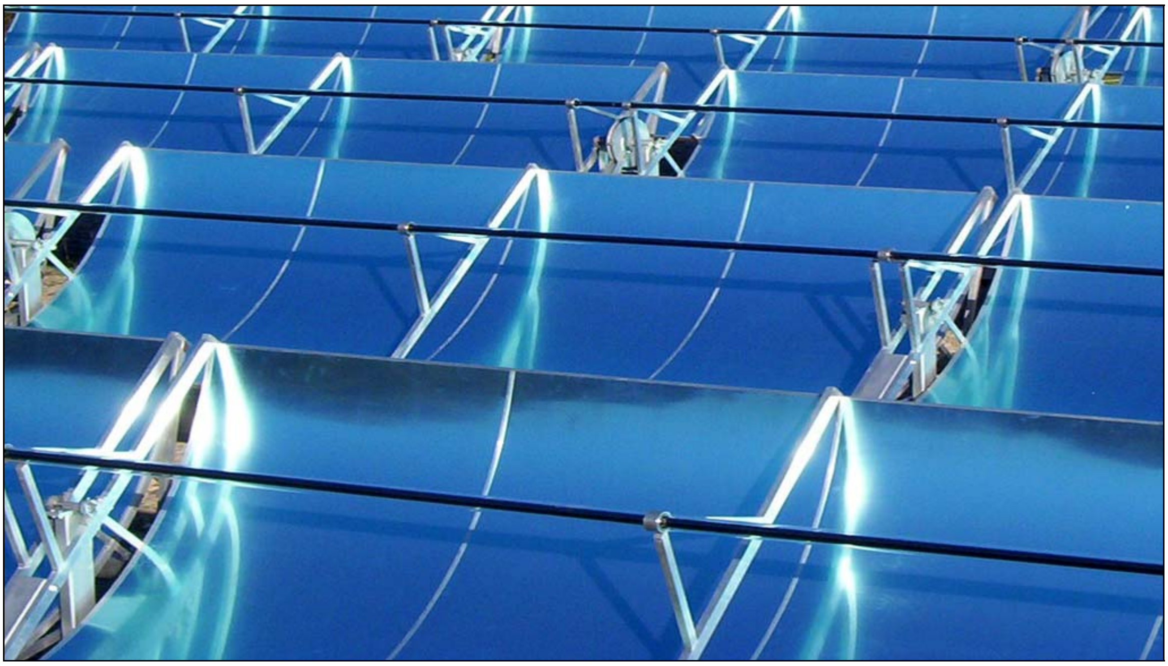
The absorption system installed at the “Iberotel Sarigerme Park” is supplied by solar generated steam with parameters of up to 4 bar saturated steam with approx. 144 °C. Furthermore, a small storage tank is needed to fit the energy demand over the day. In case the outlet temperature of the collectors is not high enough to drive the steam generator (and thus the absorption chiller), auxiliary heating with the fossil fuel boiler is necessary. In the case of “Iberotel Sarigerme Park” the system is connected to the existing steam system of the hotel, so that the remaining power can be used from the steam power supply of the hotel.

The aim was the optimal design of the components of the plant, which means the capacities of the storage tank, the boiler and especially the collector area, to cover the cold and heat demand of the building. The configuration of the plant is economically optimal, if a high level of fuel costs savings with a low capital investment can be attained. In operation, the system is regulated in a way that the greatest possible part of cold and heat load is covered by solar energy supplied by the installed collector area.

In Turkey, electricity costs are different depending on the time of day. Between 5 and 10 p.m., electricity costs are higher than during the normal tariff zone. In this high tariff zone, it is important to reduce the share of the cooling supply of the conventional cooling system, increasing the solar contribution of the SOLITEM System to achieve greater efficiency.

Energy system description

The SOLITEM PTC’s new roof mountable Parabolic Trough Collector Series for temperature levels of up to 250 °C has been developed. The collector system is tracked by a one axis tracking system and consists of modules with an aperture width of 1.8 m and a length of 5 m each. Solar radiation is focussed on an absorber tube which has a diameter of 38 mm. The focussing element is an aluminium reflector with a concentration measure of up to 30.



SOLITEM PTC 1800 collector field at Iberotel Sarigerme Park in Dalaman/Turkey

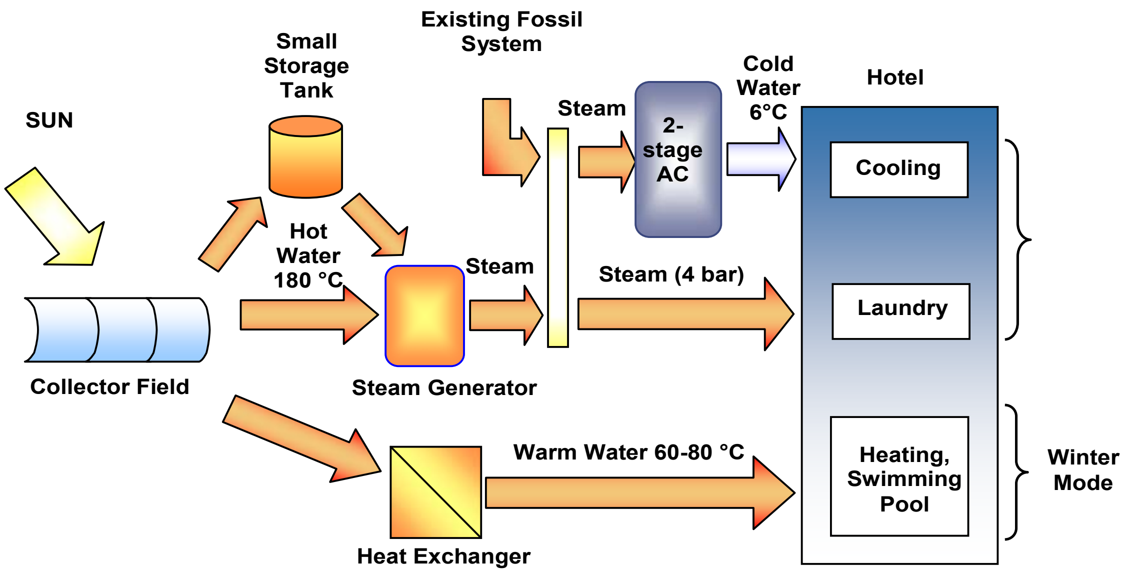
The figure shows a parabolic trough collector row of the PTC 1800 with reflector surfaces. The thermal losses at the high operating temperature level are reduced by a glass envelope tube. Out of the consideration of the higher costs, the glass envelope tube is not evacuated. The torsional stiffness is enhanced by an additional metal tube (torsion tube) behind the collector modules. A major part of the collector components are manufactured in Ankara, where a subsidiary of SOLITEM has been established. The rest of the components are produced in Germany, in Turkey and Switzerland. The tracking system of the Dalaman plant operates with wire ropes and allows the tracking of six collector rows with a number of eight modules each. A controller for two-axis tracked mirrors was modified for control requirements for the tracking of the parabolic trough collectors. A calculation of the position of the sun gives the input for an approximate positioning of the collectors while sun sensors installed in different places of the collectors provide data for a precise positioning (fine tuning) of the collectors.

The collector field of the pilot plant consists of five parallel rows with four modules each and a total aperture area of 180 m². Pressurised water is used as the heat transfer medium. The inlet temperature of the collector field is about 155 °C. 180 °C is the measured outlet temperature of the field. With a downstream steam generator, saturated steam with 0.4 MPa and 144 °C is generated.

System operation modes

The SOLITEM system has at least two operation modes. These modes are helpful to replace high fuel and electricity costs with the available solar power, which depends on general boundary conditions like price level for electricity and fuel etc. But the operation modes are also dependent on the behaviour of energy consumers, time of day and energy consumption.

SOLITEM Solar Cooling Systems based on SOLITEM Parabolic Trough Collector PTC 1800 combined with Double Effect Absorption Chillers



Operation modes of the SOLITEM System

In principle, it is possible to supply the whole hotel with solar cooling provided by the SOLITEM System, but based on efficiency, the optimal solar supply is between 40 and 80 %. That is why – at least presently – the SOLITEM System is combined with conventional systems (bivalent operation), which considerably adds to profitability. Besides, it is differentiated between high and low tariff zones depending on the time of day. In low tariff zones, in which electricity is cheaper, less cold is produced, which means that more process steam is available. In high tariff zones, when electricity is more expensive, cold is the main product of the system in order to save electricity. This operation mode is characteristic for the summer mode (cooling/process steam).

Another huge advantage is the possibility to also operate the system in winter mode (heating). In this mode, the main purpose of the system is to heat the buildings and/or swimming pools and generate hot water. The operating temperature in the collector field is lower than in summer mode with around 60 °C to 80 °C, which raises the overall degree of efficiency of the system due to lower heat losses. In winter mode, the heat of the collector field is transmitted to the warm water cycle of the hotel through a separate heat exchanger.

The absorption chiller can be operated exclusively by solar generated steam during peak load of the collector field. Because of the two-stage design, the chiller reaches 140 kW cooling capacity at the fully loaded level with a guaranteed Coefficient of Performance (COP) of 1.3 and with a cooling water inlet temperature of 29 °C. The conversion process of solar heat in chilled water for air conditioning by the absorption chiller can be fundamentally improved if it is operated on part load. In the part load operation area, the COP value can achieve up to 1.5.

During the initial phase of operation, adaptation problems occurred, which have been eliminated by the optimisation of the installation under consideration of the existing structure. Since the optimisation of the installation has been finished, the next step is to follow this year: The dimension of the system will be extended significantly by a doubling of the collector field area. With the magnification of a solar energy deposit, a thermal capacity of about 200 kW will be made available. With this energy amount, cooling demands of up to 140 kW and steam demands of up to 100 kW can be covered at the same time.

SOLITEM Solar Cooling Systems based on SOLITEM Parabolic Trough Collector PTC 1800 combined with Double Effect Absorption Chillers

Resume

The solar energy based SOLITEM air conditioning system can be operated on a large share in energy supply (up to 100 % of the power demand can be covered by the collector unit). The remaining energy is connected to the existing steam and chilled water system of the hotel. The market potential seems to be very attractive for Mediterranean countries with a large cooling demand of about 5-7 months per year. Further details of the concept will be presented at the meeting. For this example, the savings in energy and costs will be shown compared to a state of the art system. As fossil fuel is substituted by solar energy, the emissions will be reduced significantly.

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Heat pumping and reversible air conditioning; A new project of the International Energy Agency

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Abstract
Some of the most attractive heat pump applications consist in recovering the heat rejected by the condenser of a chiller already in use and in using this chiller in heat pump mode, whenever there is no cooling need. The project presented here aims to promote the best heat pumping techniques applicable in air conditioning of commercial buildings. A classification is being established among different building types, with different air conditioning systems, submitted to different profiles of internal heat gains, with different behaviour of the occupants and different control modes.
Typical profiles of yearly heating and cooling demands associated temperature requirements will be established. Design tools are being developed; they will be proposed to architects, consulting engineers and installers in such a way to reach a global optimisation of the whole HVAC system.
A methodology is also being developed and validated for optimal operation and global performances evaluation.

Introduction

A promising solution…

Substituting a heat pump to a boiler may save more than 50 % of primary energy, if electricity is produced by a modern gas-steam power plant (and even more if a part of that electricity is produced from a renewable source).
This fact is illustrated in Figure 1:
Potential savings are calculated as function of the heat pump COP, by reference to the use of a conventional heating boiler (with 90% of efficiency) and for different efficiencies of the electrical power plant (assumed to use the same fuel as the boiler).
The 50% of energy saving would be reached, for example with a heat pump COP of 3.25, associated to an electricity production efficiency of 55% (as currently reached with a combined gas-steam power plant).

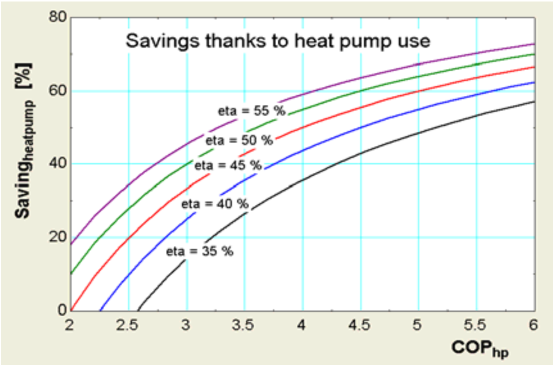

Figure 1: Primary energy savings expected from heat pump use

In fact, "Heat pumping" is probably today one of the most expedient solutions to save energy and to reduce CO2 emission.
It's probably also one of the safest solutions, because vapour compression refrigeration technology is now very robust and the characteristics of all of its components are already well known.
From other part, a lot of work has already been done in order to assess the performances of different refrigeration and heat pump systems and to open the way towards an optimal design.
Numerous pilot studies were performed during the last decades, among others in the frame of the IEA Heat Pump Program (HPP), with real heat pump systems, associated to different building types, exposed to different climates and with the use of different heat sources:
Ground, exhaust air and outside air [1][2].
Most of the results available confirm the full reliability and the high performances provided by these different techniques.

Applicable to almost all building types…
Most of the heat pump studies were, until now, concentrated on applications to new ("low" and "very low" energy) residential buildings.
But a growing attention is paid to other building types:
- Existing residential buildings to be retrofitted;
- New and existing non-residential buildings, mostly those where there exists also some cooling demand (supermarkets, offices…).

But which should be better promoted…
Except for the regions where residential cooling is a must (and where the heat pump is usually nothing else than an air conditioner used in "reverse" mode) and for a very few other ones (as Switzerland and a part of Austria) the heat pump market stays surprisingly marginal…

This moderate success might be due to the following obstacles:
- Wrong (or non-updated) information: wrong promotions were done in the seventies with poorly efficient heat pump systems, poorly efficient electrical power plants and poorly trained installers. Heat pumps gained a bad reputation at that time…
- Some « conservatism »: building designers and engineers tend to promote the techniques they know the best and refrigeration is, for many of them, a bit "mysterious"…
- Dissuasive capital costs: a (low tech) residential heat pump is sold today for 10 times the price of a (high tech) car air conditioning!
- Dissuasive running costs: Electrical energy, peak of electrical power and maintenance are still too expensive…

These obstacles might be removed, thanks to the following actions:
- Defining better the heating demands, in relationship with the characteristics of the building, with the climate, with the occupant behaviour;
- Updating the information about heat pump performances, in relationship with the heat source available and with the heating system selected;

- Developing design tools adapted to the different phase of a project, in such a way to guarantee the best integration of the heat pump inside the building - heating system;
- Developing reliable methods to evaluate the global performances and commissioning procedures to apply all along the building life cycle, with ("manual" and "BEMS-assisted") tests of functional performances;
- Conducting and documenting successful case studies.

By selecting the most attractive applications
One of the most attractive heat pump applications consists in recovering the heat rejected by the condenser of an existing chiller.
Such recovery may require to raise the condensing temperature, or to connect the condenser to an "templifier".
The "price" of the heat recovery corresponds to the supplement of electricity consumed by the existing compressor or by the compressor of the "templifier". In both cases, the corresponding COP should be very high (well above 3).
The project presented hereunder is dealing specifically with heat pumping and reversible air conditioning in commercial buildings.
Most of the existing air-conditioned commercial buildings offer attractive retrofit opportunities, because:

1) When the chillers are in use (because there is some cooling demand), there is some condenser heat to be recovered (to cover, at least a part of the heating demand which always subsists);
2) Whenever a chiller is not used for cooling, it might be re-converted into heat pump.

The design of a new building should take all possibilities of heat pumping into consideration, in such a way to make air conditioning as "reversible" as possible.
This can be achieved by using different fluids to transport the heating and cooling energy among the zones: air, water, brine and refrigerants. The last possibility corresponds to what is currently called a "Variable Refrigerant Flow rate" (VRF) system.

In Figure 2 is presented an example of three-pipe VRF system, used in three different regimes: "cooling only", "cooling and heating" and "heating only".

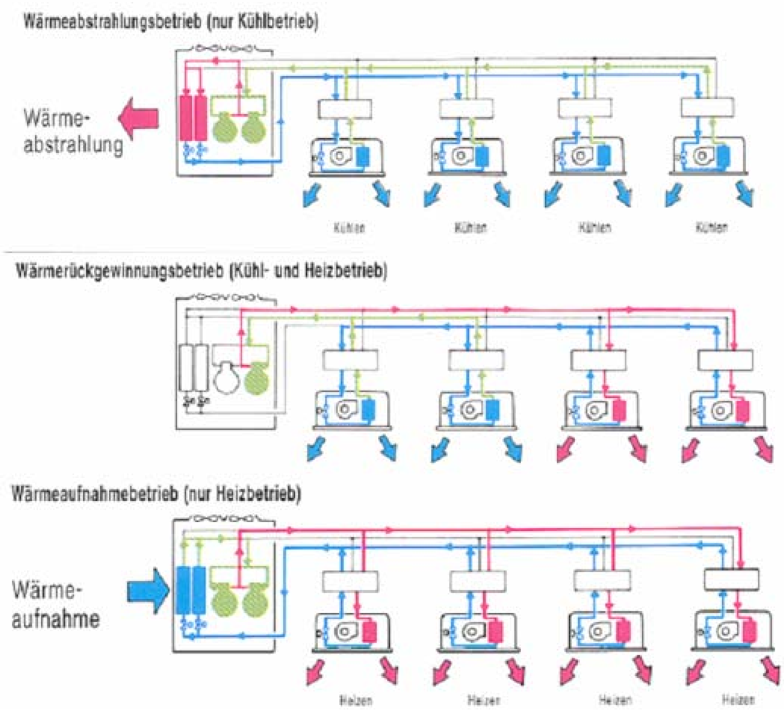

Figure 2: Example of three pipes VRF system

Such technical solution offers great potentials, but also desserves careful installation and management.
Laboratory test results indicate that the heating COP is not always reaching expectations. This is illustrated in Figure 3 where are presented some laboratory test results obtained with two different types of VRF systems. It appears that the heating COP stays always well below 3, even when the outside air temperature is floatting around 15°C.

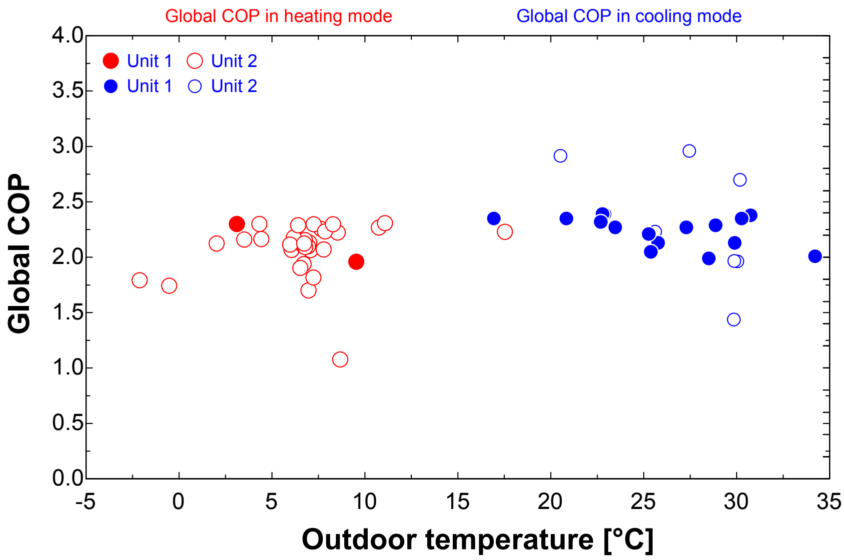

Figure 3: Examples of laboratory test results obtained with two different VRF systems

Project Description

The project presented here is developed as the so-called “annex 48” of the “Energy conservation and community systems” implementing agreement of the International Energy Agency (IEA) [3].
It started in July 2005 and is to be completed in June 2009.
The first year is reserved to the “preparation” phase; the “working” phase is starting in July 2006.

Annex 48 participants are working in close cooperation with other groups of the is being conducted in close cooperation with two other projects in preparation in the frame of the “Heat Pump Programme” IEA implementing agreement [4 and 5] and with the ASHRAE technical committee TC 9.4 "Applied Heat Pump/Heat Recovery Systems", who has already performed a feasibility study in the same domain [6].
The aim of annex 48 is to promote the best heat pumping techniques applicable in air conditioning of commercial buildings.
Focus is given to the integration of these techniques inside the whole air conditioning system.
Six subtasks are being performed in common by the participants:

Subtask 1: Analysis of building heating and cooling demands:

This analysis is performed with the help of building models already available.
A classification will be established among different building types, submitted to different climates, different profiles of internal (sensible and latent) heat gains, different occupants requirements and different control modes (Figure 4).
Special attention must be paid, for example, to the ways of humidifying and de-humidifying the air (in view of required temperatures) and to the distribution of the loads among the different building zones (in view of possible inter-zone recovery).
Typical profiles of yearly heating and cooling demands will be established.
Nominal loads (as already calculated by consulting offices and installers) can be used as starting point in this analysis.

In existing buildings, both calculated and measured data can be used.
It's indeed theoretically possible to define both heating and cooling demands on the basis of simple (electricity and fuel) consumptions records. But, in many cases, the cooling demand stays difficult to understand. Large scattering is currently observed between measuring and simulation results.

Special attention must also be paid to situations where IAQ, thermal comfort and humidity requirements are not fully achieved; discomfort penalties (or comfort energy cost) will be, as much as possible, associated to heating and cooling demands.

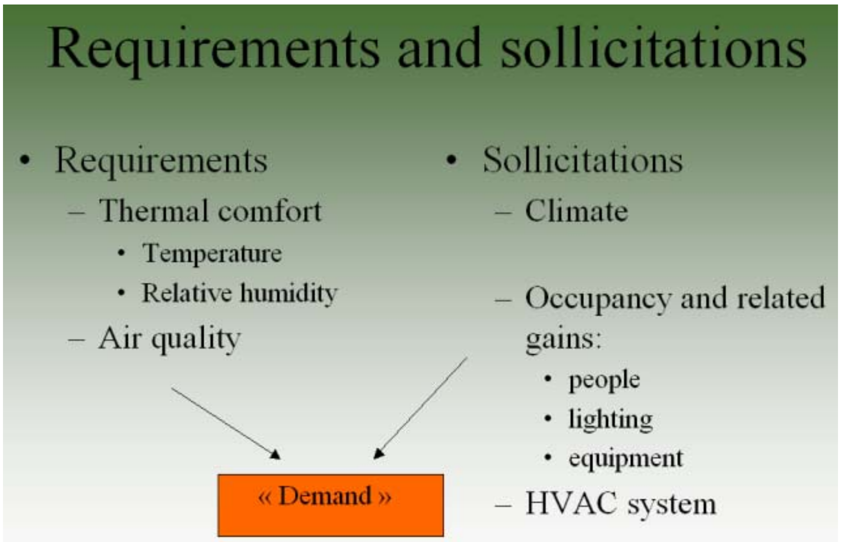

Figure 4: Definition of building heating and cooling demands

Subtask 2: Performance analysis and comparisons among the different components and systems available

Different levels of system adaptation and different control strategies must be considered.
For example, the way of controlling indoor air moisture disserves great attention:

- Higher temperature heating is required by steam humidifiers than by air washers;
- Lower temperature cooling is required by dew point air dryers than by desiccant systems…

The performances of the chillers used in direct heat recovery disserve to be carefully compared, with the use of "templifiers" and with VRF systems.
Existing (ice and stratified water) cold storage systems have also to be characterized, for a better use of the chillers in heat pump mode.
These possibilities have to be compared (in view of replacement and combination) with other energy savings techniques as free cooling, free chilling, etc.
Comparative performances of various options will be evaluated by simulation, with the help of models and reference data already gathered in the frame of previous ECBCS, SHC and HPP projects.
"Favorite" models will be identified. Preference will be given to "transparent" models (with visible equations), as in similar work already done in the frame of HPP annex 28 [7].
Special attention has to be paid to the way of defining chiller part load performances [8].
From other part, HVAC systems have still to be characterized in view of heat pumping potentials.
The actual capacities of different types of terminal units have to be carefully identified. An example of such identification is presented in Figure 5, where the heating and cooling capacities of different panels are compared.

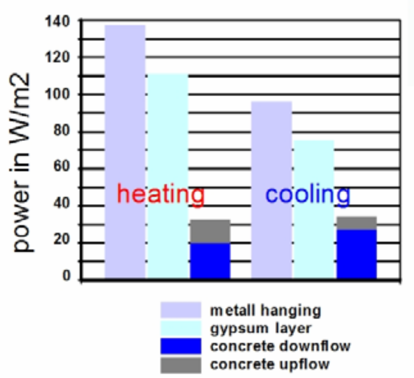

Figure 5: Comparative heating and cooling capacities of different types of panels

New products will be also considered, as, for examples, advanced heat pump systems (Figure 6).

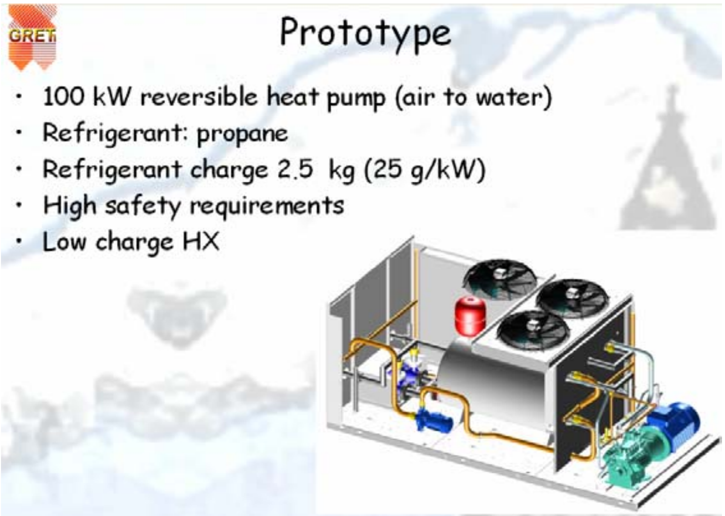

Figure 6: Example of prototype of reversible heat pump

Subtask 3: Design

A global design methodology is being developed, starting from comfort requirements and environmental constrains, and considering the best choices to do, from early stage of a project. Benchmarks, coming from the two previous subtasks, have to be used for performance evaluations. Design tools will be proposed to architects, consulting engineers and installers in such a way to reach a global optimisation of the whole HVAC system.
This will include flow charts and check lists to help in taking right decisions in right time.
Special attention will be paid to retrofit opportunities in existing buildings and to initial choices allowing further retrofits in new buildings.
Design tools will be made as flexible as possible, giving easy way to evaluate solutions at early stages (when, most of the time, ignoring what will be the actual use of the building).
Control strategies and global management of electricity demand will be carefully considered.
“Teaching the teachers” programmes will be proposed for schools of architecture, engineering and building techniques.

Subtask 4. Global performance evaluation and commissioning methods

Focus is given here on the verification of actual performances, comparison with design expectation and diagnosis.

“Follow-up” guidelines and “Fact” sheets have to be developed, in order to guarantee the best use of the system (management, maintenance and reparation).
A methodology has be developed and validated for global performances evaluation, with life cycle performance analysis and global system optimisation (including all investments, installation costs and maintenance).
Benchmarks will be proposed for these performance evaluations.
Commissioning tools already developed in the frame of other ECBCS and HPP projects [9, 10 and 11] will be tested and adapted in the domain considered.
Special attention will be paid to the selection and/or development of specific tools for:
- The audit of existing HVAC systems in view of some possible retrofit;
- The commissioning of VRF systems.

The intention is to specify the “extra-commissioning”, which might be required from manufacturer before installation, when a refrigeration system has to be used in reversible mode.
The performance verification will go up-stream, from the room to the plant: starting with verification of comfort conditions and going further only if the occupant requirements are actually satisfied (if not, it would not make any sense to verify the energy performances!)
Again here, a distinction will be made between new and existing buildings, in order to see, in each case, which requirements to formulate, in such a way to make the BEMS usable for (continuous) commissioning.
A distinction will also be made between systems assembled in factory and those assembled on site.
This subtask has close links with the new “Energy Performance” EU directives [12 and 13].

Subtask 5. Case studies and/or demonstration

Each participant is expected to propose and document at least one selected case study, on which methods and tools developed can be tested and from which reference data can be extracted.
Common simulation and evaluation exercises will be performed on some of these case studies.
In the analysis of each case study, special attention has to be paid to the identification of all its specific “surrounding conditions: climate, building type, occupant behaviour, comfort, energy regulations and prices.
Extrapolations to other possible “surroundings” will be attempted and evaluated.
Information requirements (which data, measured at which rate?) have to be, as much as possible, related to simulation models actually used.
The monitoring procedure (with or without the BEMS, on and off-line) has also to be specified.
Successful case studies will be converted into “demonstration projects”, with careful identification of their domain of interest.

Several case studies are already under consideration, for example:

The first case study proposed by Germany:

It concerns a prestigious open building, with a totally glazed façade, located near Karlsruhe (Figure 7).
Heating and cooling are provided by:
- Heat pump
- Ground heat exchanger
- Heating/cooling ceiling system
- Free cooling.

COP’s are here reaching 4 to 4.5 in heating mode and 5.6 to 8.5 in cooling mode.
The global energy consumption is of the order of 60 kWh/m2, i.e. 40 to 50 % lower than with a classical HVAC system, but there is no air moisture control and comfort conditions are not always satisfied.
From other part, the 15% of additional costs will probably never be recovered…

Figure 7: the first case study proposed by Germany

The second case study proposed by Germany:

This is another "Prestige" office building, located in Stuttgart (Figure 8).
The originality of this case consists in the integration of regenerative heating and cooling from the very begin of the project.
The installed heating power is no more than 20W/m²
The heat pump is used for heating only; the cooling is only produced by free chilling (at present time).
The schema of this system is presented in Figure 9.
Very high COP's are reached (4 to 5.5 in heating mode and 10 to 12 in cooling mode), but with still some sacrifice on comfort requirements…

Figure 8: the second case study proposed by Germany

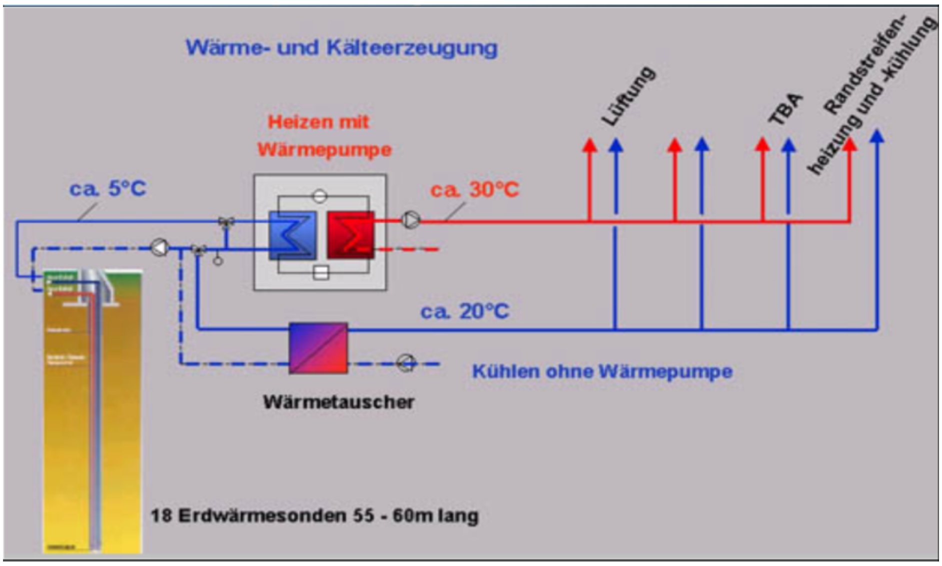

Figure 9: The heat pump system of the second case study proposed by Germany

The first case study proposed by Belgium:
It concerns an important (54 000 m²) administration building, erected in the nineties in Brussels (Figure 10).


Figure 10: First case study proposed by Belgium

The cooling plant of this building (Figure 11) seems as very appropriate for a heat recovery retrofit. Several possible options are being considered:

- Adding desuperheaters at compressors exhausts
- Rising condensing temperature
- Associating heat pumps (“templifiers”) to the condensers
- Reversing the use of the chillers in wintertime.

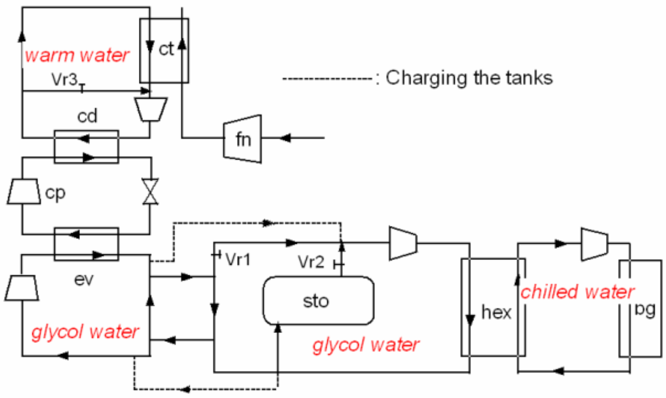

Figure 11: Cooling plant of the second case study (very simplified scheme)

The (third) option of introducing a templifier between the condensers and the heating circuit can be simulated according to the schema of Figure 12.

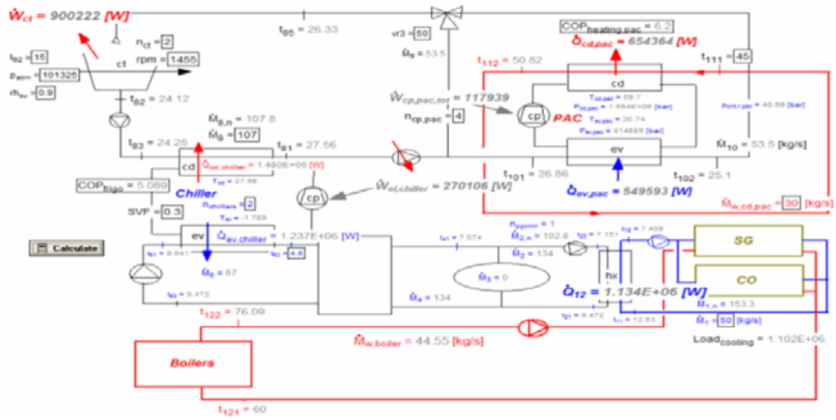

Figure 12: Hypothetical addition of a "templifier" inside the cooling plant of the second case study

Without including the fourth option (i.e. using the chillers in cooling mode only), a recovery of about 3.4 GWh of heat per year seems possible. Examples of simulation results are presented in Figure 13.

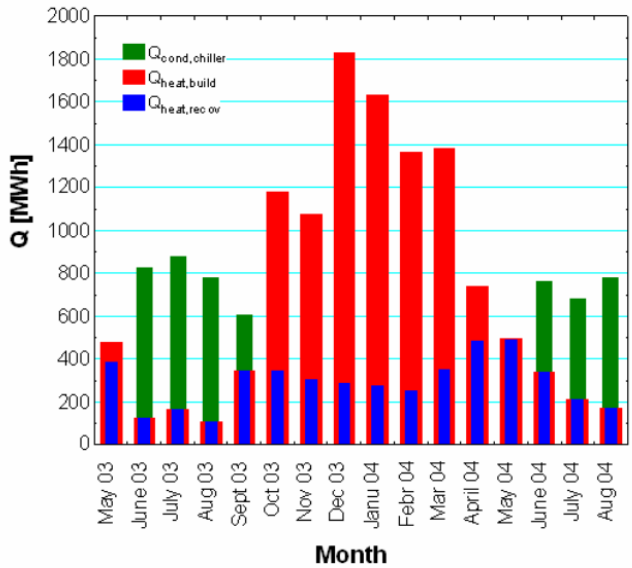

Figure 13: Heat recovery potentials with the use of a templifier

The second case study proposed by Belgium:
It's a typical medium size (28 000 m2) office building, erected in Brussels centre at the end of the sixties (Figure 14).
It contains mainly open plan offices and a few meeting rooms.
It has an old four-pipe induction units system in all offices and a few CAV/VAV systems in other zones.
The heating and cooling plant is classical: fuel oil boilers, vapour compressions chillers and cooling towers.

Figure 14: the second case study proposed by Belgium

Some retrofits were already made on the plant and on the AHU's:
An attempt of free chilling was done sometime ago, by adding a wtater-to-water heat exchanger between the condenser and the evaporator circuits (in parallel to the chillers).
For reasons still to be investigated, this experience failed and the system was dismanteled.
The AHU's were partially renovated and the replacement of all induction units and thermostatic valves is now projected.
The replacement of existing induction units by more efficient devices (other induction units or fan coils), if fitting in the small space available, should make possible to run the system with higher chilled water temperature and therefore better COP.
The environmental control should also be made more accurate.
Chiller condensers heat recovery and use of chillers in heat pump mode (when no more used for cooling) are some among many possible retrofits...

Subtask 6. Dissemination

Two or three levels of information will be defined, in order to adapt the information to all building practitioners: designers, installers, managers and deciders.
An annex 48 website is in preparation.
All other dissemination tools will be used: paper work (leaflet, handbooks), workshops, seminars, and conferences.

Deliverables

The whole work has to bring to four deliverables:

1) A tool allowing decision makers to identify the existing air conditioned buildings in which heat pumping and reversibility retrofits are the most promising;
2) A design guide for (combined) heating and cooling generation plants of both existing and new buildings;
3) A typification and selection guide, allowing to the practionners to chose and optimize, in each case, the most appropriate air conditioning system;

4) A commissioning and operation guide, allowing the manager to run the whole system in optimal conditions.

Conclusions

The project presented here is still at an early stage, but very promising results are already gathered. Most of exisiting air conditionned buildings and all the new ones are „interesting candidates“ for condenser heat recovery and also for using the chillers in heat pump mode, whenever the cooling demand desapears.

Practical experience gained in the retrofit of existing buildings should help a lot in developing design guides for new systems. The most urgent issue is to avoid irreversible choices discouraging further retrofits...

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Wind Catchers: A Review of Performance Improvement Methods

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Abstract
For centuries, wind catchers have been used in many countries especially in the hot arid zones of the world to provide ventilation and cooling without mechanical systems. But there are always barriers on extending their applicability to more modern uses.
In this paper, the principles underlying the operation of traditional wind catchers are recalled and methods used in the past, for improving their performance are introduced. Among these methods are adding evaporative cooling by different means, use of thermal mass and using domed roofs for improving ventilation rate.
While these methods were indeed more than sophisticated in their time of use, there are still shortcomings which limits the wide spread use of wind catchers in more modern buildings. To mention, just some of these shortcomings are inefficient use of evaporative cooling, limited applicability in no wind conditions and humid climates, smoke and noise control and architectural compatibility.
Through a literature review, the possible remedies proposed by different researchers, for improving the performance and widening the applicability of wind catchers are underscored. These will bring new opportunities for using this old heritage passive cooling system in today world.

Introduction
Moisture in the air holds most of the latent heat due to its heat capacity and lack of it makes the temperature in dessert areas to be very high during the day, while it is significantly cool at night. This is certainly accompanied by the physical process of radiation.

For centuries, the builders of the cities located in these parts of the world, took advantage of this key asset to build so as to keep cool during the day and warm at night. Iran is particularly rich in examples of sophisticated adjustments to harsh environmental challenges, of which wind catchers are among the most interesting ones.

In what follows, after a short review of its basic principles, deficiencies of the traditional systems are explained and possible remedies for extending their applicability and increasing their performance are presented.

Wind catcher operating principle
Wind catcher is known in different names like *malqaf*, *badgir or Baud Geer* (in Persian), *badinge*, *barjeel*, *badkhan, wind tower*, *cool tower*, *shower tower* and more recently *PDEC(Passive Downdraft Evaporative Cooler)*. To be specific, in this paper we will use *wind catcher* which is a word by word translation of Iranian *baud geer*. External views of two traditional sample wind catchers in Iran are shown in Figures 1, 2. Figure 1 is a well known garden museum and figure 2 is an old water reservoir where water below the dome was cooled by surrounded wind catchers.

Wind catcher, catches winds at higher levels, in all directions, through its scoops or in special direction heading to prevailing wind and channels it into the interior spaces of the building through the tower beneath the scoop. Air circulation in various points of the building is adjusted by opening or closing the various openers or ducts at the bottom of the tower.

The dry and warm air then may pass over a pond with a fountain to get cool and wet through evaporation. This cool and wet air flows into the room(s). In some cases wet clothes or wet date leaves were hanged on the horizontal wooden bars that protrude from the tower's walls, which had the effect of further cooling. Placing a porous pot made of clay was also common in some areas of the world. Evaporation of the water coming out of the jar (pot) cooled the air, but the extent was not so great.

Wind catcher can also provide ventilation even when there is no wind. This trick involves thermal mass. The mass of the clay built tower itself cools off at night. The following day, as the air is warmed by the sun, the tower remains cool. The air that comes in contact with the tower is cooled and, because cool air is heavier than warm air, it falls down through the tower into the space below. The same system works as a solar chimney during the night.

In addition to the simple mechanism explained above, there were some other elements in more elaborate cooling systems in Iran, a sample of which is shown in Figure 3. The extra elements which are seen in this figure are Sardab, Qanat, underground tunnel and porous pot.

Sardab (literally cool water) is an underground place, where the water of Qanat passes. It has very cold and wet air compared to the ambient air. Passing the air which comes from the wind catcher shaft from this area cools it by evaporation process.

The other element shown in figure 3 is Qanat. The basic principle is shown in figure 4. A mother-well was dug in a place far from the city where they could reach to the water table maybe 100 meters underground. They dug other wells to direct water toward the city, with minimum possible gradient.

Among the other sophisticated elements to improve the ventilation quality was domed roofs near a wind catcher. A sample can be seen in figures 1, 2. The wind passing over the dome creates a low pressure over there which leads to sucking out the warm air trapped in the inner part of the dome. The cross section and the mechanism of ventilation for domes of figures 1,2 are shown in figures 5,6, respectively.

Apart from small number of wind catchers where such complimentary devices used, most of them where simply composed of a scoop at the top and a tower or shaft as an air channel to lead outside air to the building.

Shortcoming of traditional systems and possible remedies

Traditional passive cooling systems (PCS), especially the wind catchers had some shortcomings. In fact remedies to most of these have been thought about by the heritage in different countries. What we discuss is certainly based on more in depth understanding of the physics in our date.

In this section the main problems with wind catchers and possible remedies to solve some of those problems will be shown. A review of some successful experiences around the world by different researchers is also presented, whenever possible.

1. Dust, insects and in some cases small birds enter the room

Possible remedies:

- Covering the scoop by a net.
- Increasing the height of the tower at the expense of cost.
- Making the bottom cross section larger compared to the upper cross section. In this way some settlement will be possible.
- Water spray in case of towers working on this principle solves the problem, mostly.

2. Part of the air which enters the wind catcher from the windward side, exits from the leeside without passing through the building. This applies only to those which have several scoops in different directions.

Possible remedies:

- Keeping the scoop always facing the wind. This can be down by a swivel scoop somewhat like the wind velocity anemometers.

- Removing the tower internal blade which was common on traditional wind catchers and using instead, some type of automatic louvers.

3. Thermal mass of the tower is generally low.
This makes the night cooling of the tower body, mentioned before to last only for the first hours of the next morning. After that, in the traditional towers it works more like a solar chimney.
Possible remedies:

- There is no straight solution to this as both the traditional tower's material and thickness are at their extreme. Instead in some new designs a completely non massive tower body is selected. Some of these designs can be seen in figures 7, 8. In fact the idea of thermal mass as applied to traditional wind catchers may not be applicable in new buildings. Although, the idea of combining night cooling and wind catcher, with some modifications may be applicable to the new buildings.

4. While in some cases air is passed over the fountains or a water pool, but its full latent cooling potential is not used.
There are two parameters which determine the likelihood that a drop of water will evaporate entirely under given environmental conditions. These are drop diameter and contact time between the water and the air stream. The following methods mainly work on these basics:

- Spraying water in the tower.
  The best known and addressed model of this idea is the cool tower in the Rotunda of the Expo'92 in Seville [1]. Rodriguez et al. [2] showed that in the cool tower in the Rotunda of the Expo'92 in Seville air temperature dropped by 12°C within the first meters of the tower if the mean diameter of the drops was 14μm, but if water drops of 62 μm mean diameter were sprayed, air temperature was reduced only gradually, requiring the full 15 meter height of the tower for a reduction of 11°C [3]. Givoni et al. [4] tested the performance of the same system with satisfactory results. Their work is a continuation of the PhD thesis of Dr. Nasser Al Hamiddi [5] under the supervision of professor Givoni. Brian Ford applied micronisers for atomizing the water in a passive downdraught evaporative cooling system in stock exchange in Malta [6]. Another interesting design using this concept by the same designer is Torrent research center in India [7]. Yet another report on efficient use of mist spray and rainfall sized droplets is reported in [8]. The tower for this project is shown in figure 8. The Stanford green dorm project is also another application of this method [9]. The scoop and tower of this project is shown in figure 7. And finally the last worth to mention work is due to Erell et al. presented in a recent conference in Greece [10]. They suggested more work to be done on assessing the effect of varying water flow rates in the range of 5-50 grams of water per gram of air, evaluating the effect of different ratio of coarse and fine droplets and also a more accurate measurement method. In most of the above projects, rain water is mentioned as a perfect source for the water used in cool towers because it does not have dissolved salts or minerals which can make the nozzles clogged.

- Using wetted pads in top of the tower heading the wind.
  This is like a dessert cooler or swamp cooler used extensively in the arid zones of the world. Air passes through the pads with little resistance and is cooled by evaporation of the water. In a continuation of Prof. Bahadori research on these types of modifications reported in [11], the results of a theoretical work on this type of design is shown in [12]. They concluded that for these types of wind catchers there is a maximum height after that, there is no advantage on increasing the height. Also they concluded that this type of design is the best one for places where wind velocity is low. These results are confirmed experimentally by Agha Najafi and Dehghani[13]. Chalfun also reported on successful application of this method to Botsawana Technology Center, a headquarters office building in South Africa and the Environmental Rowdah in Riyadh, Saudi Arabia [14]. He also developed CoolT, a computer program used for cool tower sizing and performance prediction [15]. A similar software, but not so interactive has also developed by Pakzad as part of his M.S. thesis under the supervision of Prof. Bahadori [16].

- Using wetted pads in top of the tower below the scoops.

Wetted pads in this design are inside the tower and are protected from direct sunlight and last longer. Three design methodologies discussed above are shown in figures 9-11.

- Using wetted columns.
  The wetted columns considered are ceramic or clay based materials. The method first revealed by Bahadori[11]. Figure 12 shows the cross-section of the design taken from a research by Badran who modified the same procedure for Jordan climate [17]. Theoretical results of Bahadori and Pakzad [12], shows that if wind velocity is adequate (at least 3 m/s), this type of design is a preferred one. An experimental evaluation by Agha Najafi and Dehghani shows the same trend, while they have some doubt in their measurement data [13]. Also, they used hanging curtains, instead of the ceramic columns mentioned in the previous paper. A shortcoming I am afraid, is the bad smell which may appear due to the wetting of the lime that is present in ceramic. This may be solved in the future by some processing if the method demonstrates it useful in other aspects.

- Porous ceramic bricks
  The principle of cooling by porous material is not new. In addition to cooling the water for drinking purposes, it was also used in wind catchers as shown in figure 13. The method is based on air being channeled around wet, ceramic surfaces to induce evaporation. By extending the idea to the new world, Papagiannopoulos and Ford used standard building bricks as the porous material within the tower of a wind catcher, supplied with water from a simple drip irrigation system [18]. The concept was further modified and named Evapcool as explained by Phan [19]. The principle of operation of the Evapcool system is illustrated in figure 14 taken from the same reference. The ambient air is let into the cavity wall from a perimeter high level opening (a). The hot and dry air comes in contact with the wet ceramic surface and is cooled by evaporation, its density increases causing downdraught (b). The air is delivered into the room through low level louvers or dampers (c) [19]. An example of this technique, as reported by Ford, et al. is Tehran Green Office in Tehran, Iran [20]. Further to the latest visit of the author from this building, it is yet under construction.

5. Loss of efficiency where the wind velocity is low.
Possible remedies:

- Using wind catcher with wetted pads (figure 10).
  As discussed above, the best choice for places with low wind velocity is pad type wind catchers [12, 13].

- Using inertia of rainfall size droplets.
  This is an interesting idea considered in some designs as mentioned in [4, 8]. Based on what mentioned by Givoni et al., “when fine droplets of water, having a very large surface area, are sprayed vertically downward, like a shower, from the top of an open shaft, the falling water entrain a large volume of air. The momentum of falling water is thus transmitted to an air stream; creating an inertial air flow down the shaft…A wind catcher can be placed above the shower head, to supplement the inertial air flow by wind effect” [4]. A somewhat different method is introduced in [8], where a combination of mist spray and rainfall sized droplets is used. The authors mentioned: ”Outside air is induced at a high level into the shower tower through the inertia of falling rainfall sized water droplets, additionally spray mist may be used to boost the rate of cooling to the incoming air” [8].

- A combination of solar chimney and wind catcher.
  This technique can help substantially by improving the ventilation rate. In fact, using the domed roof in combination to the wind catchers as shown in figures 1, 2 was based on the same idea. The idea can be applied in different forms in new buildings. A more modern application of the concept is using solar chimney or double skin facade as shown in figure 15.

- Using mechanical means as an aid. This is simply placing a fan at top of the tower to assist the air circulation. A yet another interesting innovation is the work of Erell et al. [10], where the air is drawn into the tower through two separate inlets. The main flow is generated at the primary inlet at the top. Additional air is drawn in through a secondary inlet at a lower level.

- The design of the scoops by itself has an effect on the efficiency. Pearlmutter, et al. [3] , Erell, et al. [10] and Elmualim, et al. [21], carried out theoretical and experimental investigations to evaluate the performance of different scoop geometries.

6. Limited applicability in warm-humid climate.
Just like the indirect evaporative cooling used in more humid climates, it may be possible to use the same concept in wind catchers. Givoni, et al. carried out such an investigation [4]. They used the cooled water for indirect evaporative cooling, by circulation in a closed loop in air-to-water heat exchanger inside the cooled space. Based on their results, if the shower operates day and night, and with a large mass of water, it is possible to reach acceptable daytime water temperature [4].

7. Smoke control in case of fire is more difficult.
This is a real problem and may require special equipment and or variation in codes. Regarding the equipments, fuse dampers and similar equipments could help, but need more study.

8. Managing outdoor noise
Outdoor noise is difficult to manage in a building that relies on operable windows or vents, but mates in some cases could have some acoustic improvements. Also, I believe that the ceramic type evaporators as reported in [19, 20] could solve the problem.

9. Acoustic separation between the spaces
Acoustic separation between the spaces can be difficult to achieve in a passively cooled building. A review of the most important items in natural ventilation which I found helpful in our discussion could be found in a paper by Mansouri, et al. [22]

10. Low pressure differences often require large apparatus for desired airflow rates.
This is a problem where only mechanical device can solve it.

11. Outdoor air must be clean enough to be introduced directly into occupied spaces. If filtration is required, mechanical ventilation is necessary.
Again here, I believe that the ceramic type evaporators as reported in [19, 20] could solve the problem. The water spray tower (figure 9) and the wetted pad type (figure 10,11) can also help on reducing the effect, a lot.

Climatic and architectural design

The climatic design process needs special attention. This has been already stated in 1974 Building Research Establishment the UK as [24]:

> *It is not practical to plan a building exclusively on economic, functional or formal grounds and expect a few minor adjustments to give a good indoor climate. Unless the design is fundamentally correct in all aspects, no specialist can make it function satisfactorily. Climate must be taken into account when deciding on the overall concept of a project, on the layout and orientation of buildings, on the shape and character of structures, on the spaces to be enclosed and, last but by no means least, the spaces between buildings. In other words climate must be considered at the early stage.*

In an earlier version of the present paper abstract , I wrote:

> *One of the most important aspects of passive cooling systems is that they are easy to understand and built by the architects. In that regard it is easier for them to integrate this with the total building architecture.*

Considering the above comment by BRE together with an unsuccessful project where the points raised in the BRE comment were not taken into account, .now I prefer to rephrase my above statement as follows:

One of the most important aspects of passive cooling systems is that they are easy to understand and built by the architects, but don't forget that if we do not follow BRE comments, then there is no other way to destroy the whole building and rebuild it. An incorrect selection of a pump in a chiller may be simply (but at cost) changed by the correct one, but the whole passive system, if fundamentally wrong, make big problems.

Therefore, the designer of a passive system must have adequate experience and tools for this sophisticated task.

Building bioclimatic charts

Building bioclimatic charts (BBCC) offer a way of checking whether or not a passive system is likely to produce comfortable conditions in the buildings. Givoni work is the best known one on passive systems [25]. His charts mainly based on experimental buildings of residential scale reveal the boundaries of climatic conditions within which various building design strategies and natural cooling systems can provide comfort. Lomas, et al. compared the likely internal comfort conditions in an office, as determined using Givoni BBCC for developed countries, with the conditions predicted by a detailed thermal model [26].

World climatic zones

A last comment on world climatic zones for a rough idea on the market on the modern wind catchers will be nice. One of the most commonly used classification systems for describing the climate is Koppen's [27] which is shown in figure 18. A more detailed classification exists for each country or area. All of the areas with hot-arid climates are a potential customer for wind catchers, but in their modified forms. There are also applications in other parts as discussed in this paper.

Conclusion

In this paper the basic operating principle of traditional wind catchers has been described. The main shortcomings of these systems in their basic traditional form have been highlighted and a number of possible modifications to improve the performance and widen the applicability have been reported.

The newly interest for wind catchers have a lot to learn from the heritage, but purely traditional solutions seems rather hard to apply. Combining traditional knowledge and advanced technology is therefore necessary.

The lack of real world model development is one of the factors the currently inhibit wide application of the technology. The existence of such built examples in different parts of the world provide a starting point for the research necessary to develop practical guidelines for the design of wind catcher based passively cooled commercial buildings.

Figure 1. Wind catcher in Yazd, Iran (www.yazdcity.ir)

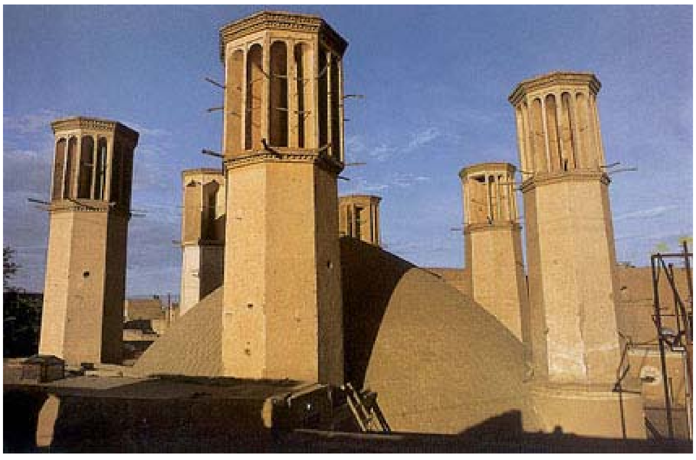


Figure 2. Wind catchers over a water reservoir (www.yazdcity.ir)

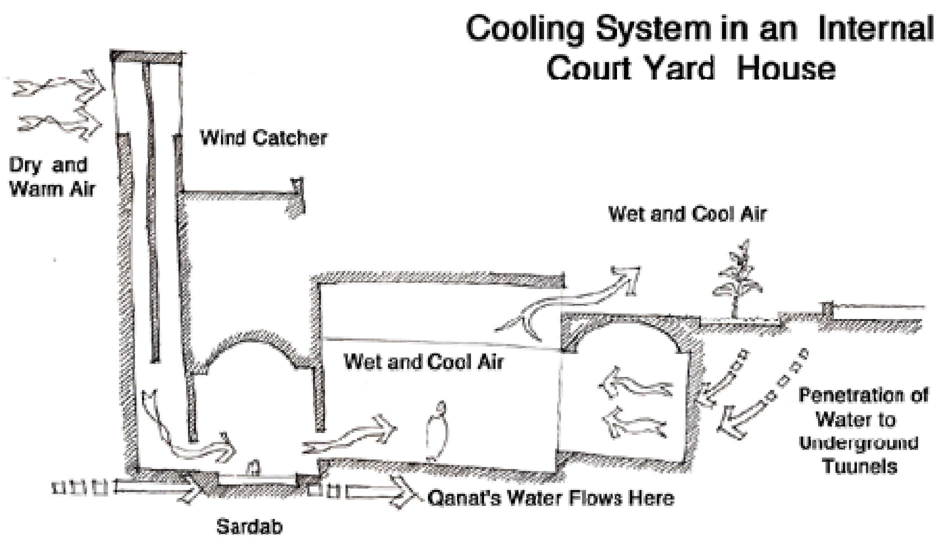


Figure 3. Cooling system with supplementary concepts
(http://www.learn.londonmet.ac.uk/packages/clear/thermal/)

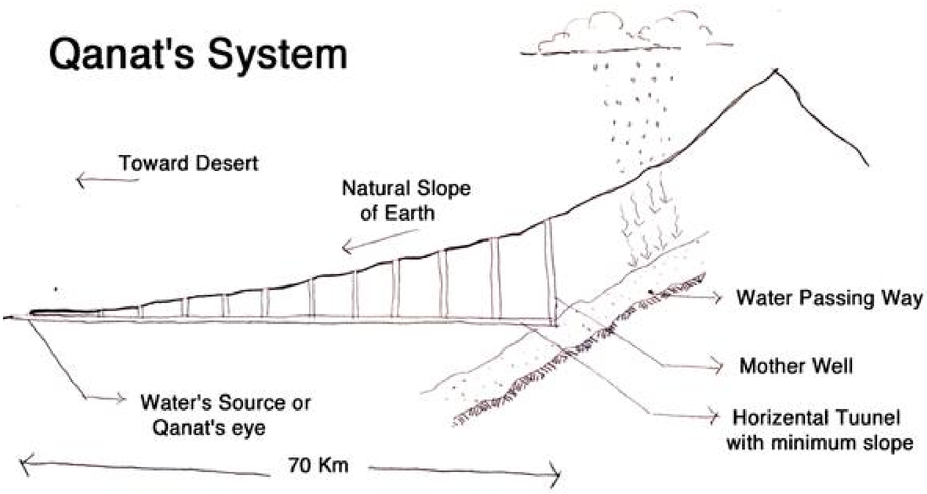
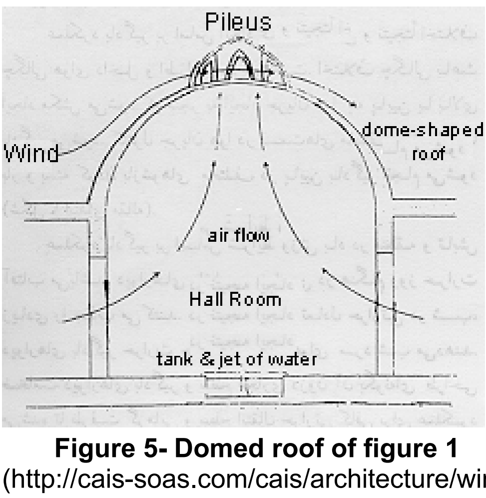


Figure 4. Qanat system (http://www.learn.londonmet.ac.uk/packages/clear/thermal/)



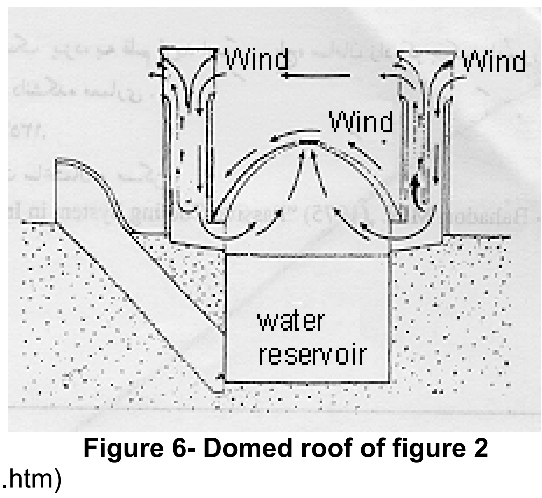


Figure 5- Domed roof of figure 1 **Figure 6- Domed roof of figure 2**
(http://cais-soas.com/cais/architecture/wind.htm)

Figure 7. Stanford green dorm project
(Aaron Rauckhorst [9])

Figure 8. Dubbo campus
(Marci Webster-mannison [8])

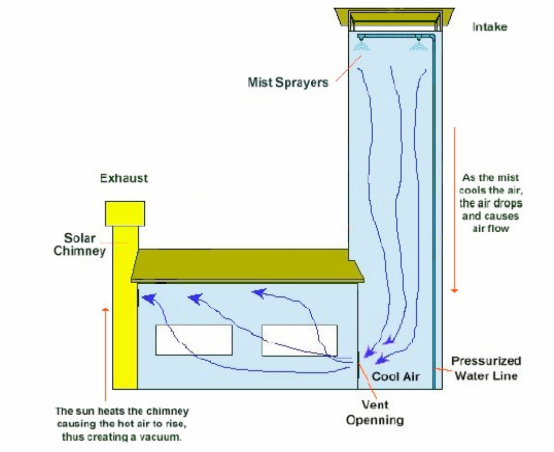


Figure 9. Design configuration of a wind catcher with water spray

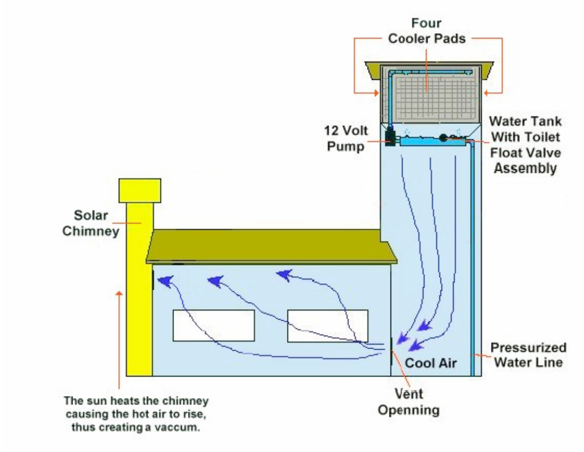


Figure 10. Design configuration of a wind catcher with wetted pads

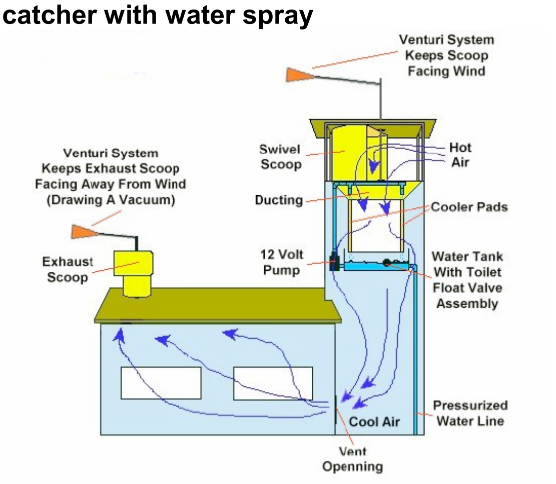


Figure 11. Design configuration of a wind catcher with modified wetted pad placement

(http://www.i4at.org/lib2/aircool.htm)

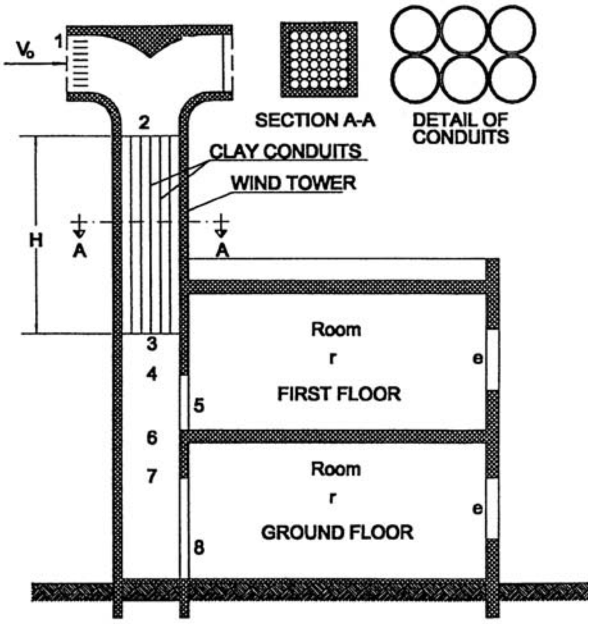


Figure 12. Wind catcher with wetted column
Badran [17]

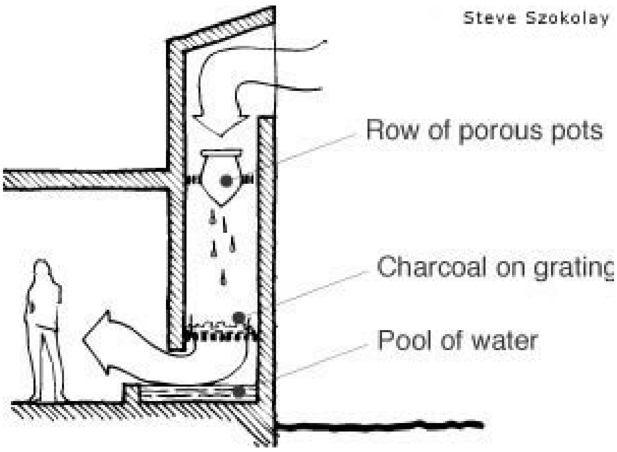


Figure 13. Traditional wind catcher with porous pot
Steve Szokolay

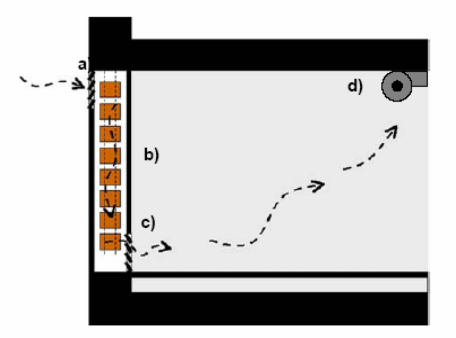


Figure 14. Evapcool system
Phan [19]

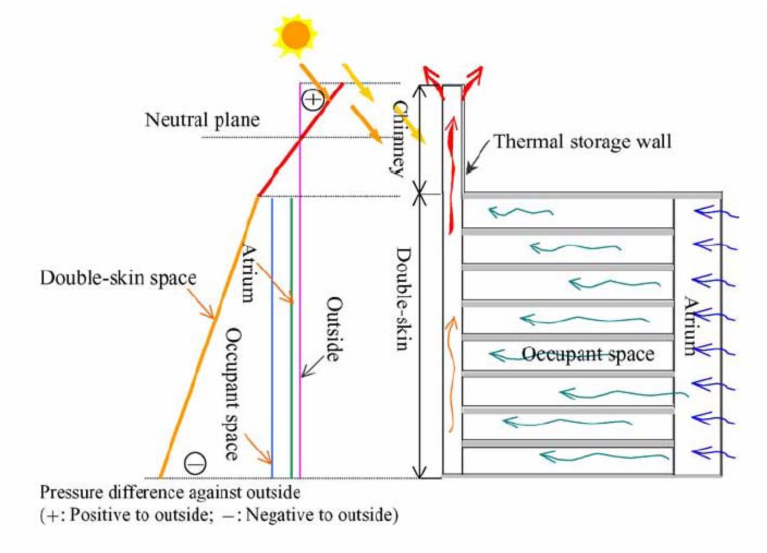


Figure 15. Double skin façade
Ding, et al. [23]

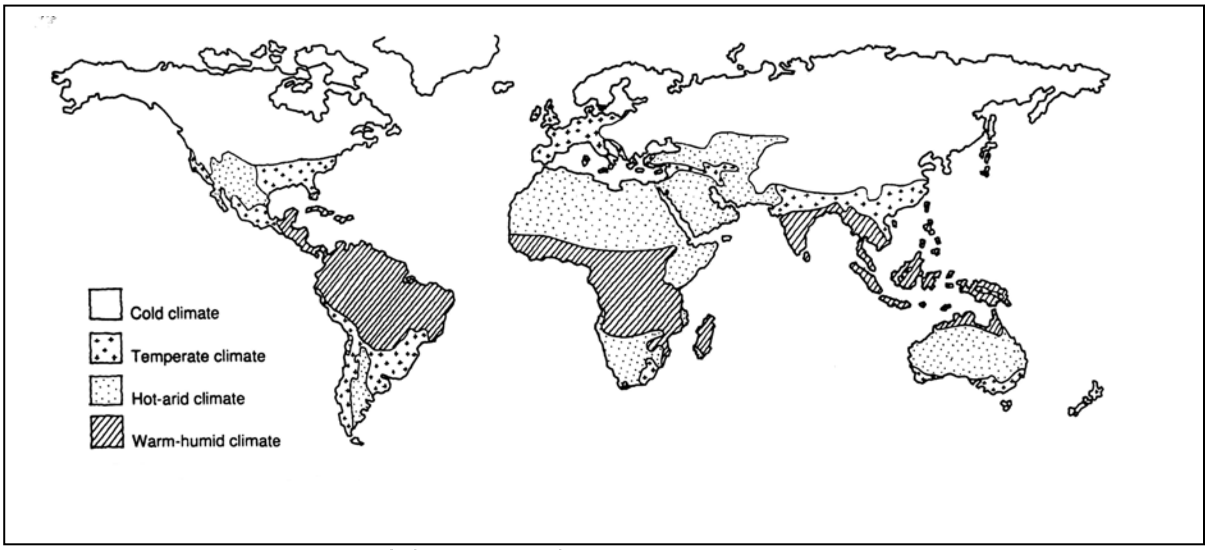


Figure 16. Main climatic zones(after Koppen)

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building
performance
congress

National and EU wide efforts to increase Energy Efficiency of installed Air Conditioners

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Abstract

Article 9 of the EPBD is named "inspection of air-conditioning systems". It stipulates that "with regard to reducing energy consumption and limiting carbon dioxide emissions, Member States shall lay down the necessary measures to establish a regular inspection of air-conditioning systems of an effective rated output of more than 12 kilowatts". Moreover, "this inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building". Finally, "appropriate advice shall be provided to the users on possible improvement or replacement of the air conditioning system and on alternative solutions".

Despite the gigantic market of Inspection created by this measure, the real objective is to realise Energy Efficient Improvement and its achievements depend on the implementation Member States will select. The real objective will be realised or missed. We stress as an important decision the one of requiring "energy experts" to make the inspection, or the opposite one, leading to the choice of "simple inspectors" to perform the work. This is related also to the choice of the reference corpus, which in the second case may well be CEN standard 15240.

Depending on those decisions, the huge cost of such an inspection will pay back in saved energy, or be lost in superficial approaches or heavy paperwork. The inspection implementation has to be a cost effective measure but also should be integrated in a framework of thought including more detailed Audits, better Operation & Maintenance and other measures for training of actors and sound decision making.

The paper is partly based on the ongoing work of a SAVE-EIE group called Auditac and including : ENSMP, France, coordinator, Eurovent, the EU manufacturers association, U. of Liège, Belgium, international experts on AC, INEGI- Univ. of Porto, Portugal, experts on AC systems, E.V.A., the Austrian Energy Agency, WSA, ABE, BRE, three UK institutions with years of experience on the subject, POLITO, modellers and researchers on systems at Politecnico di Torino, UL-FME, leading the Slovenian effort in EE.

Expectations regarding inspection

Now we have a periodic compulsory inspection in Europe, and we should try to decrease its cost and increase its positive impact. When inspection is useful, it provides information at the time needed, in a useful form, acceptable to the people who will use it. Inspection needs information to become feasible.

For instance there are potential benefits from sharing the information collected in fulfilment of the Directives inspection and certification requirements, and reducing the total workload. A good logbook would be also useful for both measures. It seems reasonable to require building owners create, use and update a logbook in order to facilitate the application of any existing or future building and energy related regulations. (In the UK, for example, Building Regulations compliance already requires the provision of a building logbook).

Who is expecting inspection results? One of the most cost effective outputs of the inspection is to question (thanks to an outside view) the way the AC system is managed and operated. On the one hand nobody knows the plant better than the operator (notably determining controls, modes and set points) or the maintainer (increasing reliability). On the other hand nobody is less interested in energy performance, reducing capacity, limiting equipment operation, etc. (except when an Energy Performance Contract has been signed, with profit sharing or fixed price arrangements).

So part of (all?) the inspection recommendations are to be transmitted by the owner to the operator, and a direct dialogue between the operator and the independent inspector is an opportunity for real world follow up. It is therefore very desirable for this direct dialogue to take place.

Collaboration between the inspector and operators/maintainers is essential for another reason. Should inspection certificates be issued for installations that we have not seen operating -and maybe cannot operate? No! So there is a need to put the plant ON even for a short time. If we want to inspect in Summer, the operator has to be present and generate an artificial cooling demand, (something that is not possible with all systems). Some systems cannot be technically inspected outside of the cooling season, but most can.

One of the outputs of the inspection, maybe the only one that the owner will always understand, is the implicit or explicit judgement on the O&M in place. As we have already discussed, there should be an obligation to maintain the “as-built” documentation and the log-book to avoid extra costs in the inspection process. The inspection report should say whether the maintenance regime in place appears to correspond to the contract or not. A good Inspection report will say where the contract can be improved. It is important to adjust Inspection time step to maximise this benefit (for instance one year after the start of a new O&M contract, one year before its end).

A number of technical actions (benchmarking, checking of equipment references, checking of maintenance contracts, etc) could well be made at distance, via phone and fax. Inspection infers presence and visualisation, but the degree should be commensurate with the potential for savings, and it may not be cost effective to visually inspect all equipment.

- Visible O & M errors, certainly. A 5-10% potential is quoted by « experts » for such errors, easy to correct if the diagnosis is expressed in the terms of the operator and takes into account the real operational constraints that the operator withstands.

- Invisible O & M errors, difficult without short-term monitoring or use of BEMS data , and without some kind of modelling of the ideal behaviour of the plant to be compared with the real one. A 10-40% potential is quoted by « experts » for such errors, but the effort to (possibly) achieve this is clearly beyond that envisaged by compulsory inspection.

- Benchmarking with other plants of the same type and age. This is certainly information that the owner would appreciate, and that only an independent inspector can bring. The knowledge is dramatically missing.

- Improvements that can be made to the hardware. This needs a lot of expertise and engineering even to produce raw estimates. The (probably conservative) estimate of the potential for savings made in EECCAC is 50% of present energy consumption.

This brings us to projects like Auditac, supported by SAVE-EIE. AUDITAC is a project about the issues that follow after the national legislation to implement Article 9 of the EPBD. The focus of the project is to help the European A/C market to reach a higher overall energy efficiency, by taking benefit of good inspections, of improved audits, of best practice case studies, or of any other measure.

The only direct and certain benefits of implementation of article 9 are the discovery of visible operational errors. Beyond this, compulsory inspection can provide indirect help to the next stages towards achieving savings, by systematically documenting what has been inspected. It would be valuable for national implementations to require standardised documentation.

An example of the life of a system and of one of these events is represented in Figure 1.

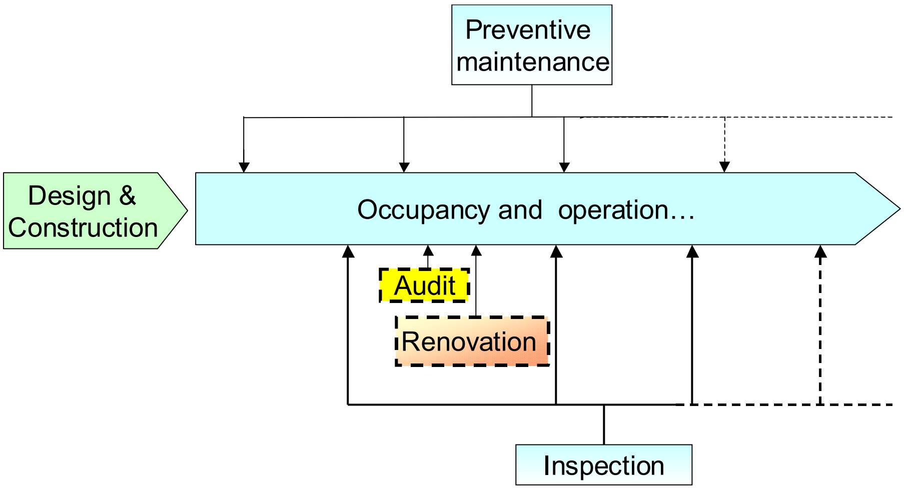

Figure 1. Lifetime of an AC plant with various steps

We can imagine four scenarios for a profitable effect of the compulsory inspection beyond the discovery of immediate operational errors.

The first benefit of the regular inspection for the building owner will be to generate a continuous awareness that there is one (or various) more or less complex AC plants, a source of some potential problems (scenario 1). Indeed, most of owners need evidence that the performance of their building is degradated before taking actions. The poor performance of an installation compared to its initial (or expected) efficiency can be due to:

- a dysfunction of air-conditioning induced by a fault on one piece of equipment
- a lack of operation or maintenance
- a control problem
- an improper action of the operating staff or occupants
- poor (obsolete) equipment compared with present standards

If we target the inspection at expenditure (scenario 2) the regular inspection could create the economics of the possible complete or partial renovation of the air-conditioning installation or the change of mode of operation. If this looks significant it would become relevant for the building owner to pay for an energy audit. But in order to enter into that circle the inspection report should identify the share of total costs (energy, O&M, investment) corresponding to the AC function. One could imagine that this is part of the Energy Certification of Buildings in the same EPBD, but it is unlikely to be (a breakdown of energy consumption by service is likely to be provided in some Member States, but is not a requirement). So only the inspection could start this financial approach. Any reference to costs will naturally increase the relevancy, the interest and the impact of inspection for building owners. The total cost can be benchmarked with “service” contracts proposed by outside operators (or intractors).

At the same time, the requirement that the inspection is independent of installers, operators, etc in the Directive is not helpful to the provision of “energy services” as it seems to require the (few) owners that have already optimised their HVAC with good energy service contracts to pay again for something already done. This would be addressed if the requirement can be a satisfied by a system of independent auditing and checking of registered inspectors – who could be existing O&M or energy service contractors.

If Inspection is the real start of an equipment Audit (scenario 3) it should start by comparing the specific plant with state-of-the-art plants. An installation can work perfectly and be correctly operated and maintained without being energy-efficient. Actually, the term “energy-efficient” is absolutely relative and depends on comparison with a reference or level of performance.

The inspection will thus highlight potential savings and – where economically justified - accelerate the replacement of air-conditioning systems or components by more efficient new ones. The inspection may focus on sizing that has to be closer to cooling requirements, on the appropriate choice of equipment, based on life-cycle costs (purchase + operation), on possible improvement of both process and building and finally on best available technologies on the market.

There is a fourth possible view on the benefits of a compulsory Inspection : preparation of a refurbishment (scenario 4). The methods should in that case also be adequate to the objective.

What does the text dealing with inspection for air conditioning facilities really say?

The new compulsory AC inspection is timely because of the age of the stock and the lack of awareness of actors who can benefit.The basic concept is necessarily constrained - it should: be possible in a relatively a short time, not require intrusive measurements, produce a precise list of defaults or possible improvements, be consistent between inspectors , be compulsory, be carried out regularly, …However, it is only the first – but very important - step that initiates the process leading to energy-efficiency by accelerating the replacement and upgrading of Air-Conditioning Systems.
Scope of inspection in Article 9

Article 9 of the EPB Directive takes care for the first time of the Inspection of existing air-conditioning systems. The idea of the European Union was then to impose a certain type of pre-audit in order to launch the process. The compulsory inspection was therefore developed in order to incite building owners (ad other actors) to make afterwards energy audits and maybe more.

Article 9
Inspection of air-conditioning systems
With regard to reducing energy consumption and limiting carbon dioxide emissions, Member States shall lay down the necessary measures to establish a regular inspection of air conditioning systems of an effective rated output of more than 12 kW.
This inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building. Appropriate advice shall be provided to the users on possible improvement or replacement of the air-conditioning system and on alternative solutions.

Many air-conditioning systems also provide ventilation, but nothing in the directive is said explicitly about “ventilation” (although there is a draft CEN standard on inspection of ventilation systems). While energy consumption of ventilation-only system can be significant, health and comfort issues relating to the provision of ventilation are very important.

Article 9 of the Directive focuses on the efficiency of air-conditioning systems and their sizing. (Over-sizing is financially wasteful but is not necessarily wasteful of energy for system whose peak performance is at part-load). The Energy Performance Certification requirements in other articles of the Directive should, in principle, encourage building designs that reduce the loads that systems have to satisfy – and should encourage passive design solutions.

However, the Directive is surprisingly silent on the issue of internal environment and comfort. Energy efficiency gained at the expense of poor indoor conditions may be a poor bargain. We have already noted that the productivity benefits (or losses) of poor performance are likely to be financially comparable or greater than the energy benefits. The optimal solution may involve a trade-off between, say, overheating risk, and system sizing or design. Although there would be some real difficulties in implementation, it would be desirable to enlarge the concept of “inspection” (and energy audit) in this direction

The comparison between Article 9 and Article 8 will tell us more about the limits and meaning of article 9.

Article 8, relating to the inspection of boilers and heating systems gives some explicit options for implementation. Article 9 does not do so, but Member States do have some latitude about a number of aspects of implementation. For example, they could adjust inspection to align with national O&M standards and coordinate it with other types of mandatory inspections on AC installations (F-gas, cooling towers). It may be possible to combine it with verification that safety regulatory requirements are met.

Article 8 (heating) has different inspection requirements for different situations. For air-conditioning there is no requirement to cover the full system at each inspection: it would be possible to have more frequent inspection of the cold or heat generating equipment and less frequent whole-system inspections. For example, there could be a one off inspection at the standard end of life of the system, or the frequency could vary with system capacity. For smaller equipment direct inspection might be substituted by some remote inspection.

Despite the lack of f knowledge and previous experience in the inspection of air conditioning, the introduction of article 9 was opportune and timely.

Over the last 20 years, the scale of application of air-conditioning in European buildings has greatly increased and, consequently, so has the importance of the associated energy consumption and carbon emissions. The age structure of the stock is such that a growing number of systems now need to be renovated or replaced (after 10-15 years of operation). This presents an opportunity to upgrade their efficiency. This can be seen from figure 1. By comparing the stock of systems in use in a given year (expressed in square meters served) with that 10 or twenty years before the number of such systems can be inferred . Out of the 2.200 Mm2 of air conditioned building area in use in 2010 in Europe, 800 Mm2 will be more than 15 years old

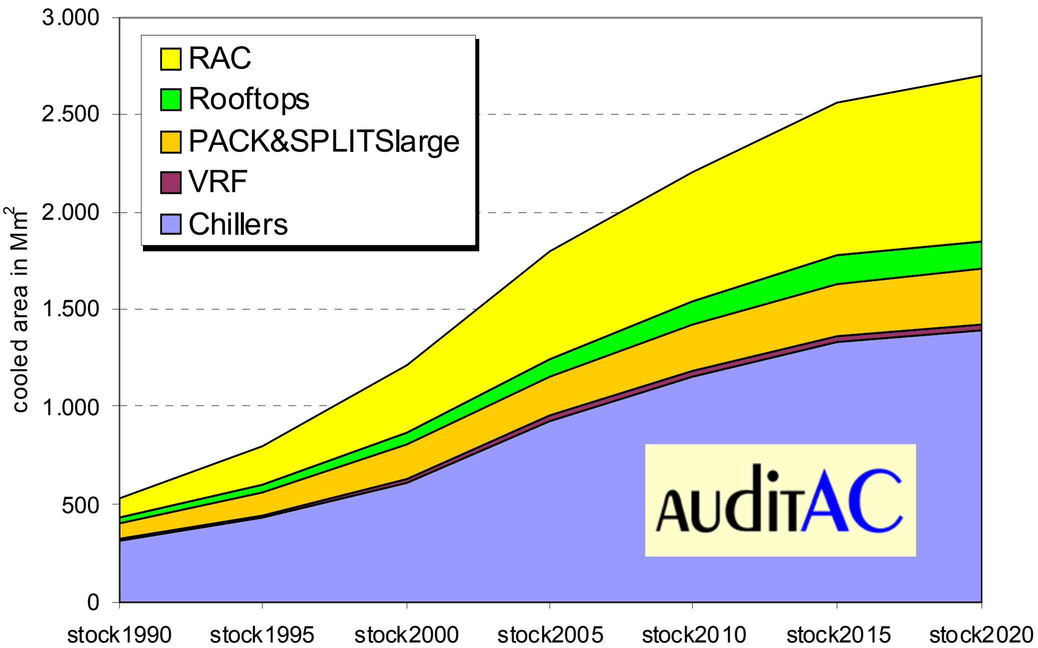

Figure 2. Cooled area (Mm2) in Europe (source EECCAC)

The age of installations is not a problem in itself, if they are of good performance and well maintained and efficiently operated. Unfortunately this cannot be guaranteed, since AC is still a relatively recent innovation and many professionals are not as familiar with the technology as they are with other building services. Building owners are often not as aware of the potential for energy savings as they could be.

In addition to savings from better operation and maintenance, the availability of systems and equipment today with much better performance than those on the market 10 years ago provides a substantial saving potential. A SAVE Study (EECCAC) showed that this potential was of the order of 50 % of current consumption.

Inspection only succeeds if it results in an audit

Inspection is meant as a "starter". Are we ready for the next phases? A rational actor will need to go through various steps to improve energy-efficiency:

- Manage and benchmark his systems and their consumptions. This can be done by every building-owner using very little information but well located indicators.
- A pre-audit (or inspection) usually carried out either as part of some other process (such as a change of use, or within a maintenance operation) or because the indicators reveal a problem, now due to EPBD. It typically requires one or two days work, usually by a professional, supplemented by existing records and "spot" measurements and allows the identification of easily identifiable faults and possible improvements
- An audit (or detailed audit) necessarily carried out by a professional, typically to further investigate opportunities identified by the pre-audit. It produces quantative estimates of the costs and saving to be expected It can take from several days (say 5 to 10) to several months (1 to 6) if long-term measurements are needed.
- If justified, investment in renovation or replacement of the system or components. Before a decision on investment is made, it may be necessary to obtain detailed quotations and make more detailed assessment of the likely savings. This we call an "investment grade audit".

This rational approach is not common, especially in the case of AC. It is well known that in order to generate financial savings, industries and building occupants' investment priority is their "core business". However, spending money to improve "utilities" is often pre-judged to be less rewarding: a serious barrier to energy-efficiency.

Clearly, from a business perspective, the financial criteria applied to investments in energy efficiency should be the same as those applied to other business investments. For many businesses, the loss of productivity that results from poor environmental conditions will be at least as financially important as energy costs. This aspect is not normally addressed by energy auditing, but could usefully be considered as part of a full audit.

For air-conditioning in buildings, the lack of established procedures for assessing the potential for savings and the shortage of visible precedents by other businesses are additional hurdles. In comparison to industry, an additional difficulty with buildings is that there can be several persons with diverging interests: the building-owner(s), the occupant(s) and the operator(s) of the technical installations. This is called the problem of "split incentives".

In principle, every actor linked to a building can in theory be interested in a pre-audit. After that, each actor is free to invest in a detailed audit before any investment. The new compulsory inspection required by Article 9 is a type of pre-audit that is ruled by a national regulation. However the Devil is in the details of implementation : does inspection prepare the next phase or not? The basic concept is necessarily constrained - it should: be possible in a relatively a short time, not require intrusive measurements, produce a precise list of defaults or possible improvements, be consistent between inspectors , be compulsory, be carried out regularly, …However, it is only the first – but very important - step that initiates the process leading to energy-efficiency by accelerating the replacement and upgrading of Air-Conditioning Systems. Let's now see those implementation issues

Implementation issues for mandatory inspection

First issue : extent. The EPBD defines an air-conditioning system as “a combination of all components required to provide a form of air treatment in which temperature is controlled or can be lowered, possibly in combination with the control of ventilation, humidity, and air cleanliness”. Moreover, “the effective rated output (expressed in kW) is the maximum calorific output specified and guaranteed by the manufacturer as being deliverable during continuous operation while complying with the useful efficiency indicated by the manufacturer”. However, even after defining those terms, article 9 remains unclear because the 12-kilowatt limit can be defined in several ways. Member States will have to define the meaning of the 12-kilowatt limit through a cost/benefit analysis. That limit is associated on the one hand to an energy saving potential and on the other hand to a workload (number of inspections). It can be :

- 12 kW per cooling system. Lower workload, smaller target of savings.
- 12 kW per zone.
- 12 kW per building. Higher workload, larger target.

The first definition is really simple and any building owner can easily determine eligible equipments by looking at nameplates. Indeed, any central air-conditioning (CAC) system is necessarily taken into account. However, most of room air-conditioning (RAC) systems and certain distributed air-conditioning systems (such as water loop heat pump systems) are not included in the scope, thus reducing the energy saving potential of such a measure.
The third definition assumes somebody knows that there are 12kW in the same building.
Globally, the inspection must avoid introducing distortions into the air-conditioning market. Indeed, too heavy, too long, too frequent and thus in short too constraining and expensive procedures for the building owner could lead him to buy equipment not covered by inspection.

Second issue : the exigency. An inspection could be a “pass or fail” test or an inspection that you always “pass”. It seems to be the second case in the directive. The CEN draft standard tries to define conditions for repetitions of the inspection when the results are unsatisfactory, but this is not an easy task. In that case, the penalty would not be to “fail” but to have to pay more frequently the auditor who would come again and report about the same thing. Obviously Member States are allowed to develop better, less arbitrary or more productive approaches. This could be the case for defects which existed at the time of initial installation and were prohibited by regulations at that time. In the existing projects, non compliance with regulations is not always reported.

Third issue : are thermal regulations useless when we move to inspection? Neither the CEN draft nor national drafts on inspection rules make reference to any regulations in force at the time of inspection or, previously at the time of construction. Obviously, regulations applied to buildings differ from one Member States to another so that it is impossible to quote them all in the text. However it seems logical that such an inspection should check if the building and technical installations included respect the regulation in force or not (at the time of installation or/and now). As these regulations are improved regularly, the inspection should also regularly propose improvements to owners in order their buildings reach the latest and stricter energy and environment standards. These verifications should in theory be part of the technical basis of the regular inspection in order that future regulations will be applied more quickly to the existing stock. The same EPB directive requires Member States to introduce a thermal regulation of building renovations and an energy certification of existing buildings that may require pre-audits. Shouldn’t we look for a synergy when applying both articles of the same directive?

Fourth issue : compliance. Many inspections will not be realised, should we just ignore that fact? Local authorities have the list of buildings on their area and it could be possible to crosscheck it with local taxes in order to determine the ownership. The existence of an air-conditioning system and the determination of the quantity in a building would need a costly local survey. After that, the update of the equipment database must also be made in real-time. This systematic approach may be too costly so that a simpler system will be used. A possible approach is to require proof of inspection at the time of the time of sale or lease, as for Energy Performance Certification. Some countries like France have AC as one item in the IPPC list. By changing the threshold (presently 50 kW elec. In the case of France) this powerful tool would help to provide a better coverage of inspection measures.

Comparing costs and benefits of the inspection according to type and size of system and qualification of staff needed

A recent study (Dupont, 2005) separated the market for air-conditioning between first installations and replacements . For example, with a (universal) 15 year system lifespan, the renewal market in year n is the difference between total apparent markets in years n and n-15. Figure 2 is extracted from this paper.

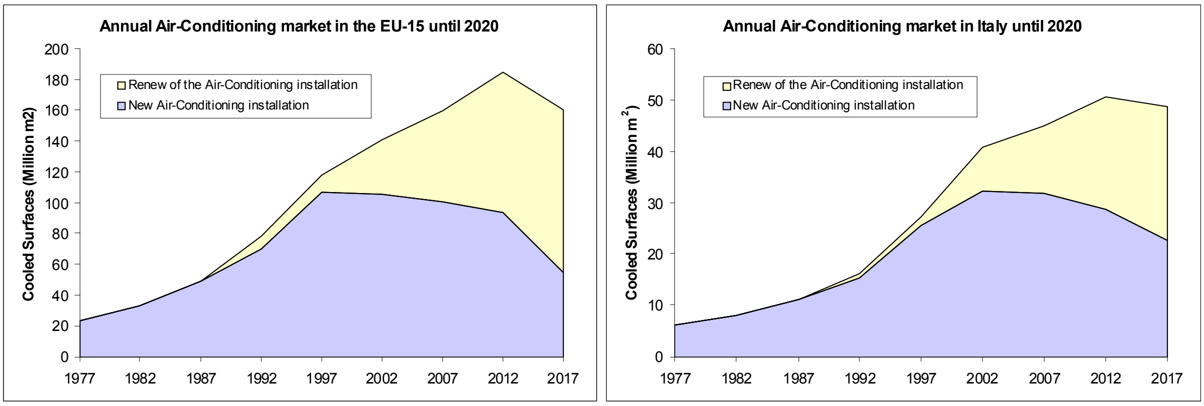

Figure 3. Prediction of annual Air-Conditioning markets in the EU-15 (left) and Italy (right) according to Dupont's paper at ECEEE

The size of the installed stock can be used to estimate the size of market for of audits and inspections. The breakdown of sales could be used to generate estimates of the demand for audits for older systems. The results for inspections are presented in the following tables for five countries as numbers of "orders" per year. The total number of inspection is the sum of inspection of systems with a unitary capacity over 12 kW (CAC) and of buildings deserving inspection because they host various small systems (RAC)

	2007		**2012**		**2017**	
	RAC	**CAC**	**RAC**	**CAC**	**RAC**	**CAC**
Italy	628000	181900	828000	237000	962500	279600
Spain	405000	124400	490500	151100	545400	167500
France	311300	64300	405100	84200	477900	98600
Germany	239200	42400	322900	57300	384100	68000
UK	161700	54600	191300	64200	205700	69800

Inspection of air-conditioning installations is quite different from, for example, car safety inspection because it is focused on efficiency. Although good maintenance is part of good performance, there are other factors (behaviour, operation, adjustments, control system, equipment) that have large consequences on the efficiency of the system. All these factors must be analysed and the inspector should give advice on possible improvements. The CEN draft focuses on visual observations without quantitative tests. We do not yet have standard procedures such as exist for car safety inspections. A balance has to be struck between the level of expertise required of inspectors and the scope of the advice that they can be expected to give. To maximise energy-efficiency benefits, they need to be experts in air-conditioning and building. If the requirement for independence is interpreted to exclude installers and maintainers this will restrict the pool of possible inspectors, probably to HVAC consultants.

We can imagine two scenarios concerning the people in charge of inspecting air-conditioning installations. On the one hand, if inspection requires "energy experts" or "air-conditioning experts", Member-States will have to certify consultants for doing it. However, they will not be able to spend all their time on that activity. On the other hand, if inspection requires only "simple inspectors" without engineering expertise, it is possible that they spend the majority of their time on the periodic inspection. We can then make the following illustrative assumptions:

- 1 day on average to inspect a building
- 200 inspections per year on average for a “simple inspector”
- 100 inspections per year on average for a consultant with a real expertise in air-conditioning or energy
- Inspection every 3 years

The number of persons necessary for the inspection resulting of our assumptions is given in the following table per Member-State

	2007		2012		2017	
	Inspectors	**Experts**	**Inspectors**	**Experts**	**Inspectors**	**Experts**
IT	4050	8100	5325	10650	6210	12420
SP	2650	5300	3210	6420	3565	7130
FR	1880	3760	2450	4900	2885	5770
GE	1410	2820	1900	3800	2260	4520
UK	1080	2160	1280	2560	1380	2760

The energy saving that will result from inspection is difficult to evaluate. There is a direct potential associated to the correction of visible defects limiting the operational performance, but also an indirect potential from possible consequent actions by the building owner. The indirect potential is especially difficult to estimate because it depends on the extent of the opportunities revealed by inspection and the proportion of them that building owners are prepared to finance. Therefore, the direct potential is unlikely to be larger than 5-10% of the Air-Conditioning energy consumption.

In order to evaluate the costs and the benefits of inspections, we made the following assumptions in addition to the previous ones:

- A consultant with a real expertise in air-conditioning or energy is in charge of the inspection
- The tariff (French practice for an expert consultant) for inspection would be 1000€ per day
- The price of the electricity in 2007 is between 20 and 40 €/MWh (current range on POWERNEXT, EEX, OMEL and UKPX)
- An average saving potential of 10% of the Air-Conditioning consumption
- Air-Conditioning consumption ratios (kWh/m2) determined by simulation from the EECCAC study (J. Adnot et al. 2003)

Estimated costs and benefits of the inspection are given in the upcoming table. The payback periods are longer than the expected intervals between inspections so (with our assumptions) inspection does not look directly cost-effective. Moreover, this 5-10% potential is likely to decrease with time because some defaults will be more often checked afterwards. Rising energy prices would have the opposite effect. In terms of climate change policy, the appropriate metric is cost per tonne of carbon emissions abated, but we have not examined this.
As we have explained, we have not assessed the indirect effects. If the direct cost of an audit were, say, twice that for an inspection and the potential savings were also doubled, the payback periods (ignoring investment costs) would be as in the table. In most cases, these are comparable with the expected life of systems so, when investment costs are added, it seems unlikely that the economics will be favourable. However, this analysis treats all systems as being identical.

Estimates of the costs and benefits of the inspection per Member-States for 2007

	Cooled Surfaces (.10^6 m^2)	**Consumption Ratio (kWh/m^2)**	**A-C Consumption (TWh/yr)**	**Cost of Inspection (.10^6 €/yr)**	**Saving Potential (.10^6 €/yr)**	**Simple payback (ignoring any investment cost) (years)**

IT	370.4	50.1	18.6	810	37.2 – 74.4	11-22
SP	407.7	81.5	33.2	530	66.4 – 132.8	4-8
FR	268.1	32.6	8.7	376	17.4 – 34.8	11-22
GE	185.3	22.8	4.2	282	8.4 – 16.8	17-34
UK	166.2	19.7	3.3	216	6.6 – 13.2	16-33

This illustrative analysis suggests that inspections and audits should be targeted. Inspection will be mandatory, but focussing the scale and frequency of inspection on systems likely to offer the greatest potential would beneficial. Alternatively, including inspection within routine O&M would reduce the cost (the "independence" requirement would have to be met by independent auditing of registered inspectors). A similar argument applies to voluntary audits: inspection reports should help to focus attention. When systems or components are due to be replaced, the marginal investment costs for higher efficiency (over and above the unavoidable costs) and the marginal analysis costs (over and above design costs) should both be reduced and the expected future lifetime is long, so this seems to be an obvious target area.

Our conclusion : the necessity to learn very quickly from experience

As it bacame apparent, there are many unknowns and much to learn from experience. The Member States in charge of this measure (and only body in charge of it) should try to learn from this unprecedented experience that they are conducting. Each of them will follow a distinct pathway. We recommend that they build a strong agreement on objectives (types of saving targeted, magnitude of expenses on average) and use at maximum their freedom on means to make that an experiment, with a common monitoring of field results. Then, the experience feedback would allow the creation of an harmonised procedure meeting the cost effectiveness criteria.

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Measured Building and Air Conditioning Energy Performance: an empirical evaluation of the energy performance of air conditioned office buildings in the UK.

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Abstract

Building on previous papers presented on this topic at IEECB 2004 and IEECB 2002, this paper presents further findings from an energy monitoring study of the energy and carbon performance on air conditioning systems in 32 UK office buildings over a period of three years with the aim to aid the development of improved guidance on the appropriate use of air conditioning systems, and to help identify strategies to achieve national carbon emissions reduction targets.

This paper focuses on the building energy use and carbon emissions from 27 buildings in which the air conditioning systems have been monitored derived from energy billing data and monitoring and targeting (M&T) data. The results presented include analysis of the overall energy consumption and associated carbon emissions of each building studied, comparisons to the relevant UK national benchmarks, breakdown of energy use by fuel type and identification of the proportion of energy used and carbon emissions attributable to cooling purposes.

The results indicate that current UK national Office energy consumption benchmarks are probably set at the correct level, and also show that the higher overall energy consumption of air conditioned buildings is NOT inherently due to the use of AC systems, but is as much to do with other building end-use. The buildings monitored with low HVAC energy consumption did not necessarily lead to energy savings at the building level.

Introduction

The European Directive on the Energy Performance of Buildings (EPBD)[1], the promise of Emissions Trading Schemes (ETS), and fears about the security of energy supply. These are all strong drivers that are already changing the way we design our buildings. These drivers all have a common theme: they place a much greater emphasis on designing low carbon emission buildings and services.

One area that is marked out for particular scrutiny by current and forthcoming legislation is the energy consumption, and hence carbon emissions, of air conditioning systems. However there is very little information on actually how much energy AC systems consume when used in the real world, with all the imperfections this brings in design and maintenance, and which factors influence this consumption the most.

Aiming to fill this information gap, research undertaken at the Welsh School of Architecture[2] set out to collect empirical data on the actual performance of air conditioning systems 'in practice' in UK office buildings. The information collected would aid the development of improved guidance on the appropriate use and selection of air conditioning systems and help identify strategies to achieve the UK's national carbon emissions reduction targets.

This research has measured the energy consumption, and hence associated carbon emissions, of a number of air conditioned office buildings and their services 'in use' between April 2000 and December 2002.

The primary findings for this work focused specifically on the performance of the air conditioning systems have already been presented at a number of conferences[3,4,5] and further publicised in journals[6,7,8] and a project web-page[2], but the headlines include:

- Chilled ceiling and beam systems appear to be the most efficient way of providing comfort cooling in UK Offices where appropriate.
- Direct expansion (DX) cooling-only systems to a lesser also have the potential to be very efficient, but often fail to achieve their potential performance in practice due to poor operation.
- The control of the systems studied showed a response to internal loads, seasonal and daily variation in climate, but time control was typically poor. On average operating almost twice as much as expected indicating that a 50% saving in energy consumption and carbon emissions may be possible from more effective time control alone.
- Analysis of the part-load profiles of the systems studied showed that the majority of the systems generally had twice the capacity required for the actual loads served over the monitoring period and this over-sizing maybe in part due to current design practices which appear to over-estimate the internal cooling loads actually found in practice.
- All the generic types of air conditioning studied appear capable of meeting current UK ‘good practice’ energy consumption standards for comfort cooling on an individual basis, emphasising the importance of appropriate control, maintenance and operational management.
- A strong correlation was observed between recent computer design modelling of ‘good practice’ energy consumption and the monitored results suggesting that current modelling techniques appear accurate for comparative design assessment, but are less accurate at predicting actual energy performance of a given site without detailed operational parameters.

Overall the research to date has shown that AC systems as currently used in the UK show the potential for substantial improvements in system Carbon emissions performance, and significantly these improvements can be accomplished through existing technology.

Further analysis of this work is now underway[9] including a detailed analysis of fabric and solar loads in the office buildings studied[10,11] and analysis of other data collected including that discussed by this paper which focuses on the building energy use and carbon emissions from the buildings in which the air conditioning systems have been monitored.

The results presented include analysis of the overall energy consumption and associated carbon emissions of each building studied, comparisons to the relevant UK national benchmarks, breakdown of energy use by fuel type and identification of the proportion of energy used and carbon emissions attributable to cooling purposes.

Building Energy Consumption & Carbon Emissions

This section discusses the whole building energy consumption, and carbon emissions, from the buildings in which the air conditioning systems have been monitored. The whole building energy consumption data has been derived from site energy bills, or monitoring and targeting (M&T) data, collected with the owner’s permission at each site. The data was collected with the aim of determining the overall energy consumption of each building relative to national benchmarks and to determine the proportion of energy consumed by air conditioning systems through comparison to the system performance data previously published.

The overall whole building energy consumption, and calculated carbon emissions, for each of the buildings studied is summarised in Table 1. The Table shows the total annual energy consumption for each building by each fuel type, the total delivered energy consumption, and the associated annual carbon emissions. All these values have been normalised to the treated floor area (TFA) of each building.

Table 1: Summary of Annual Whole Building Energy Consumption & Carbon Emissions

Site # / System Type	Electricity	Gas	Total Delivered Energy	Carbon Emissions
	kWh/m²	*kWh/m²*	*kWh/m²*	*KgC/m²*
Cooling Only Systems				
Site 1 - All-Air	215.6	13.0	228.6	31.3
Site 2 - All-Air	284.4	51.5	335.9	43.2
Site 3 - All-Air	n/a	n/a	n/a	n/a
Site 4 - All-Air	389.5	232.4	621.8	68.1
Site 5 - All-Air	294.9	226.9	521.8	54.4
Site 6 - All-Air	290.0	235.7	525.7	54.1
Site 7 - All-Air	204.3	130.0	334.3	36.2
Site 8 - Chilled Ceiling	247.3	99.3	346.5	40.6
Site 9 - Chilled Ceiling	n/a	n/a	n/a	n/a
Site 10 - Chilled Ceiling	76.9	141.0	217.9	18.7
Site 11 - Chilled Ceiling	159.9	0.9	160.9	22.8
Site 12 – Fancoils	286.1	67.2	353.4	44.3
Site 13 – Fancoils	232.6	9.8	232.6	33.6
Site 14 – Fancoils	352.7	165.9	518.6	59.2
Site 15 – Fancoils	n/a	n/a	n/a	n/a
Site 16 – Fancoils	n/a	n/a	366.4	32.4
Site 17 - DX Split	n/a	n/a	n/a	n/a
Site 18 - DX Split	137.6	168.2	305.8	28.8
Site 19 - DX Split	438.2	85.0	523.2	66.9
Site 20 - DX Split	110.5	n/a	110.5	15.7
Site 21 - DX Split	112.1	42.8	154.9	18.3
Site 22 - DX Split	153.1	20.8	173.9	22.9
Site 32 - Unitary HP	147.6	166.3	313.9	30.1
Average	***229.6***	***109.2***	***334.0***	***38.0***
Standard Deviation	***102.0***	***81.1***	***149.1***	***16.3***
Reverse-cycle Heating & Cooling Systems				
Site 23 - Chilled Ceiling	407.7	n/a	407.7	57.9
Site 24 – Fancoils	252.6	n/a	252.6	35.9
Site 25 - DX Split	334.8	42.0	376.8	49.9
Site 26 - DX Split	558.5	n/a	558.5	79.3
Site 27 - DX Split	558.5	n/a	558.5	79.3
Site 28 - VRF HR	252.6	n/a	252.6	35.9
Site 29 - VRF HR	166.5	26.4	193.0	25.1
Site 30 - VRF HR	256.5	91.5	348.0	41.5
Site 31 - VRF HR	334.8	42.0	376.8	49.9
Average	***347.0***	***50.5***	***369.4***	***50.5***
Standard Deviation	***137.9***	***28.3***	***128.4***	***18.9***

The total annual delivered energy consumption of the buildings studied ranged from 110.5kWh/m2 to 621.8kWh/m2, which translates into associated carbon emissions of between 15.7kgC/m2 and 79.3kgC/m2. These measured values compare well to the range of energy consumption we expected, which was between 225kWh/m2 and 568kWh/m2 based on the national benchmark

standards[12]. Only Site 4 consumed more energy than expected and a number of sites consumed significantly less than expected indicating better than good practice energy performance.
It is interesting to note that on average the energy consumption of the buildings using reverse-cycle air conditioning systems was 10% higher than those using separate heating and cooling systems. The buildings with reverse cycle systems consumed 369kWh/m2 and the buildings with separate systems consumed 334kwh/m2 on average. Theoretically the reverse cycle air conditioning systems should provide heating more efficiently than gas-fired heating systems in terms of delivered energy, so it is slightly surprising that the buildings that used reverse cycle systems consumed more energy than those that used separate heating and cooling systems. However there are too many variables involved in the whole building data to draw conclusions on the performance of the reverse cycle systems compared to other types of heating system at this point.

In terms of annual carbon emissions the slightly higher energy consumption of the buildings using reverse-cycle systems is exacerbated by the higher emissions of their electrically driven energy, emitting more carbon emissions per unit of energy consumed, leading to 33% more carbon emissions on average than the buildings using separate gas-fired heating systems.

Comparison to Building Energy Consumption Benchmarks
The total annual delivered whole building energy consumption of the twenty-seven buildings for which data was available is shown in Figure 1 relative to the UK national energy consumption benchmarks for whole building Office energy consumption by fuel type.

When compared to the benchmarks it is evident that the buildings studied represent a broad cross section of the UK stock of office buildings in terms of their energy consumption as the recorded building energy consumption ranged from only 49% of good practice (Site 20), indicating very low energy consumption by national standards, up to 154% of typical practice (Site 4), and indicating high energy consumption by national standards.

The comparison to the benchmarks shows that eight of the twenty-seven sites (30%) were high energy consumers, with consumptions higher than typical practice, and six of the sites (22%) were low energy consumers with energy consumptions lower than good practice. The remaining thirteen sites (48%) of the buildings studied had energy consumptions between good and typical practice standards indicating ‘normal’ or ‘typical’ energy performance.

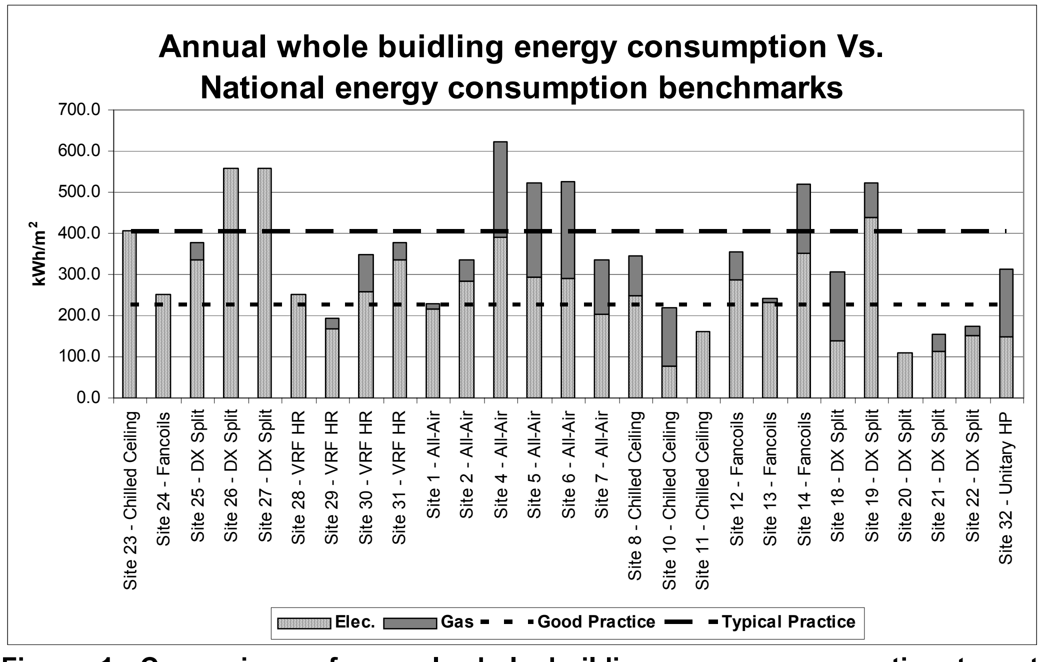

Figure 1: Comparison of annual whole building energy consumption to national energy consumption benchmarks for air conditioned office buildings.

Since the benchmark standards assume upper and lower quartiles for typical and good practice energy performance, i.e. the consumption of the upper and lower 25% of the building stock are considered high and low energy consumers respectively, they compare favourably to the 30% above typical practice and 22% below good practice energy performance of the buildings studied here. Assuming the building sample is broadly representative of the overall UK building stock of air conditioned buildings this also suggests that the current national energy consumption benchmarks for whole building energy consumption are set at the correct level.

Comparison to Building Carbon Emissions Benchmarks
The total annual building energy consumption of the buildings studied in terms of their associated annual carbon emissions are shown relative to the national carbon emissions benchmark standards for air conditioned office buildings in Figure 2 below.

Not surprisingly, the associated whole building carbon emissions data demonstrate similar relationships to one another, and the national benchmarks, as the energy consumption data discussed in the previous section. The exceptions are sites 20, 23, 24, 26, 27 and 28, which only used electricity and due to the higher emissions per unit of energy of electricity compared to natural gas meant that in terms of carbon emissions these building appear to perform less well compared to the other buildings and the national benchmarks.

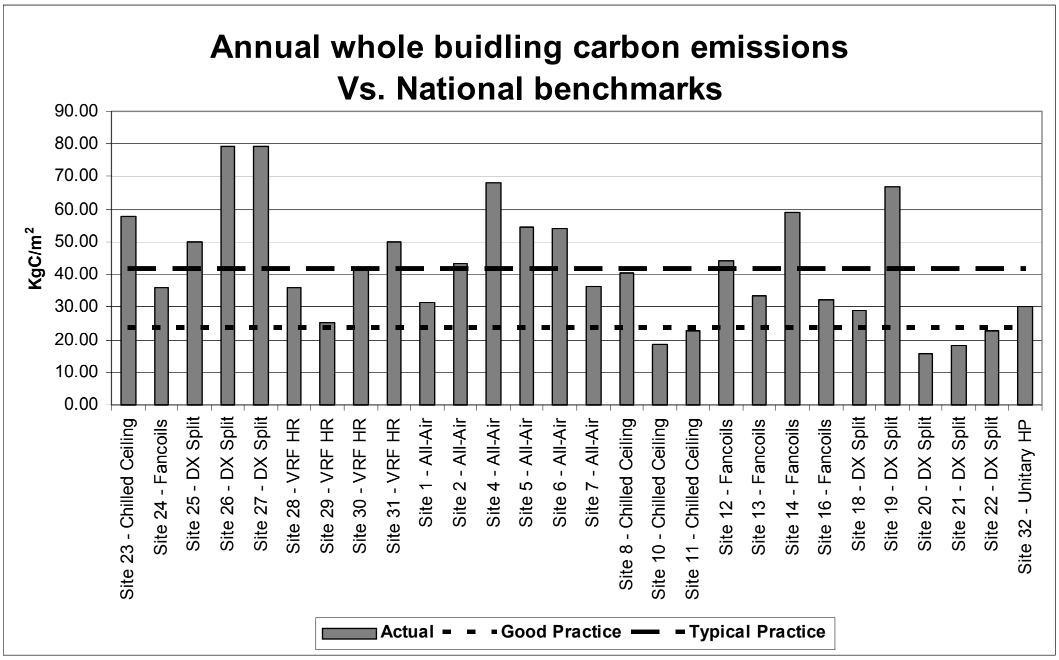

Figure 2: Comparison of annual whole building carbon emissions to national benchmarks for air conditioned office buildings.)

Proportion of Energy Consumed by Air Conditioning

This section uses the measured whole building and system energy consumption data previously published[2] to assess the proportion of energy consumed by the air conditioning system in each building studied. The proportion of building energy consumption, and carbon emissions, of the buildings studied used by each air conditioning system is shown in Table 2 expressed as a percentage of the whole building consumption and emissions.

Overall the proportion of energy consumed by the cooling only systems ranged from 3% to 43% of the whole building energy consumption and 21% on average. The proportion of energy used by reverse cycle air conditioning systems was 39% on average and ranged from 17% to 67 % of the whole buildings energy consumption.

This compares favourably to the expected proportion of energy consumption which ranged 16% to 23% for the cooling-only and 44% to 62% for the reverse-cycle systems. The only systems that proportionally used less than 16% of the whole building energy consumption for cooling were ones that had better than good practice energy consumption.

The proportion of carbon emissions attributed to the air conditioning systems are slightly higher than the proportion of energy consumption, because they are electrically driven with higher emission per unit of energy than other types of fuel. On average these accounted for 26% and 41% of the emission of the buildings with cooling only and reverse-cycle air conditioning respectively.

Table 2: Measured annual AC system energy consumption and carbon emissions

Site # / System Type	Annual Energy onsumption	Annual carbon Emissions	Proportion of Energy	Proportion of Emissions
	(kWh/m^2)	*(KgC/m^2)*	*% kWh*	*% KgC*
Cooling Only Systems				
Site 1 - All-Air	36.0	5.1	16%	16%
Site 2 - All-Air	37.8	5.4	11%	12%
Site 3 - All-Air	41.7	5.9	n/a	n/a
Site 4 - All-Air	164.4	23.3	26%	34%
Site 5 - All-Air	90.3	12.8	17%	24%
Site 6 - All-Air	104.2	14.8	20%	27%
Site 7 - All-Air	99.0	14.1	30%	39%
Site 8 - Chilled Ceiling	22.8	3.2	7%	8%
Site 9 - Chilled Ceiling	17.1	2.4	n/a	n/a
Site 10 - Chilled Ceiling	6.8	1.0	3%	5%
Site 11 - Chilled Ceiling	23.3	3.3	14%	15%
Site 12 – Fancoils	102.2	14.5	29%	33%
Site 13 – Fancoils	55.3	7.8	24%	23%
Site 14 – Fancoils	38.1	5.4	7%	9%
Site 15 – Fancoils	108.1	15.4	n/a	n/a
Site 16 – Fancoils	151.6	21.5	41%	67%
Site 17 - DX Split	57.2	8.1	n/a	n/a
Site 18 - DX Split	23.0	3.3	8%	11%
Site 19 - DX Split	35.9	5.1	7%	8%
Site 20 - DX Split	47.8	6.8	43%	43%
Site 21 - DX Split	44.5	6.3	29%	35%
Site 22 - DX Split	69.4	9.8	40%	43%
Site 32 - Unitary HP	98.2	13.9	31%	46%
Average	***64.1***	***9.1***	***21%***	***26%***
Standard Deviation	***43.0***	***6.1***	***13%***	***17%***
Heating & Cooling Systems				
Site 23 - Chilled Ceiling	70.5	10.0	17%	17%
Site 24 - Fancoils	104.6	14.9	41%	41%
Site 25 - DX Split	160.4	22.8	43%	46%
Site 26 - DX Split	128.3	18.2	23%	23%
Site 27 - DX Split	230.3	32.7	41%	41%
Site 28 - VRF HR	159.1	22.6	63%	63%
Site 29 - VRF HR	131.1	18.6	68%	74%
Site 30 - VRF HR	102.7	14.6	30%	35%
Site 31 - VRF HR	92.6	13.1	25%	26%
Average	***131.1***	***18.6***	***39%***	***41%***

Standard Deviation	***47.6***	***6.8***	***18%***	***19%***

Current energy consumption standards lead us to believe that air conditioned office buildings typically use at least 50% more energy than similar non-air conditioned buildings[12] but, based on these results, the provision of cooling by air conditioning systems on average only accounted for 21% of total building energy consumption. Therefore air conditioning systems on their own do NOT account for all the extra energy typically consumed by air-conditioned buildings compared to non-air conditioned buildings.

The measured data also indicates that the low energy consuming air conditioning systems lead to a reduced proportion of building energy used for cooling, but not necessarily also to reduced whole building energy consumption. For example, Site 19's air conditioning system had a better than good practice energy consumption, and accounted for less than 7% of the total building energy consumption, but the whole building was a high energy consumer with annual energy consumption 30% above typical practice.

This indicates that the underlying reasons for 'air conditioned' buildings consuming more energy, and hence producing more carbon emissions than 'non-air conditioned' buildings is NOT necessarily, or inherently, due to the use of air conditioning to provide cooling. The relatively high energy consumption of 'air conditioned' buildings compared to 'non air conditioned' buildings appears to be as much to do with other energy-use and not just air conditioning. Indeed this other energy end-use could well be the reason for the building have A/C in the first place.

This issue is illustrated in the buildings monitored in this study by that fact that 46% of the air conditioning systems performed at good practice level or better, but only 22% of the buildings also performed at good practice levels. Air conditioning energy efficiency, as a major energy user in buildings, is clearly important to achieving good overall energy and carbon performance, but as the last point emphasises air conditioning systems cannot be considered in isolation from the building and its other energy uses.

Conclusions

The data and results discussed in this paper provided analysis of the overall energy consumption and associated carbon emissions of 27 UK air conditioned office buildings each buildings. The energy consumption of the entire buildings studied showed that the total annual delivered energy consumption of the air conditioned office buildings studied ranged from 110.5kWh/m2 to 621.8kWh/m2, which translates into carbon emissions between 15.7kgC/m2 and 79.3kgC/m2 of treated floor area.

These values are similar to the range of energy consumption expected from the current UK energy consumption benchmarks for air conditioned office buildings and this agreement suggests that the sample of buildings studied by the research is broadly representative of the UK stock of air conditioned office buildings, and also that the current national UK energy consumption benchmarks are probably set at a correct level.

The proportion of energy consumed by the cooling only systems ranged from 3% to 43% of the whole building energy consumption and 21% on average. The proportion of energy used by reverse cycle air conditioning systems was 39% on average and ranged from 17% to 67 % of the whole buildings energy consumption. Significantly the data shows that buildings with lower energy consuming A/C services resulted in a lower proportion of the whole building energy consumption and not reduced whole building energy consumption.

Importantly this indicates that the underlying reasons for 'air-conditioned' buildings consuming more energy, and carbon emissions than 'non air-conditioned' buildings, is NOT inherently due to the use of air conditioning but primarily due other energy end-use within the building, such as lighting and small power office equipment.

Therefore any serious attempt to reduce energy consumption and emissions from UK office buildings needs to target improvements not just at the HVAC systems, although obviously important, but also equally at the other energy end-users. As a result any savings made to lighting or small power equipment loads should also result in energy savings from the air conditioning system as cooling loads will be reduced. But furthermore it is evident from the range of energy consumption at both the system and building level presented that the potential for savings compared to current practice are considerable.

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Effect of the Certification on Chillers Energy Efficiency

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Eurovent Certification

Abstract

Energy efficiency has become one of the most important issues for HVAC industry. Indeed, the implementation of Kyoto Protocol has now a high priority for the European Union and strong measures should be applied to achieve its targets, like an 8% reduction of equivalent CO2 emission between 2008 and 2012. For our industry, the best way to meet this important challenge is to be proactive and propose relevant actions in advance instead of waiting for some mandatory measures decided by the European Commission or the National Authorities.

Within this framework, two important measures have been decided by Eurovent Chillers Manufacturers. The first action, February 2005, was the implementation on a voluntary basis, of the classification for chillers. The objective of the classification is double:

1. Promote the more efficient chillers
2. Facilitate the elimination, in the near future of the low efficient ones.

Based on existing chillers presented to Eurovent certification, the limits between classes have been defined, for gross EER, for each type of chillers. It is now easier for consultants, engineers and technical specialists to select efficient chillers from Eurovent directories, www.eurovent-certification.com.

The second issue was the use of the chillers and the real annual energy consumption. As the part load efficiency has a very strong impact on energy consumption, Eurovent has initiated the SAVE study, EECCAC-Energy Efficiency and Certification of Central Air Conditioners. An integrated energy efficiency index called ESEER –European Seasonal Energy Efficiency Ratio-, equivalent to IPLV-Integrated Part Load Value- developed in the US and used by ARI, was established for the European conditions. The study was finalised in 2004, the experimental application started in 2005 and the mandatory implementation for Eurovent manufactures is scheduled for June 2006. From the certified part load table, Eurovent will compute ESEER allowing the comparison of chillers performances in the cooling mode. This global single figure shall be published in Eurovent directory together with cooling capacity and power input for standard conditions at full load.

This paper presents the evolution of chillers efficiency, analyses Eurovent chillers classification after one year of implementation, describes Eurovent certification for European Seasonal Energy Efficiency Ratio for chillers and gives an overview of next steps for chillers certification.

Introduction

According to EECCAC-Energy Efficiency and Certification of Central Air Conditioners- project (1), the cooled area in 2010 in Europe will be 2200Mm². These expectations are confirmed by the ever growing number of chillers sold in Europe every year, as shown in Figure 1. As a consequence of the increasing of the installed units, the electrical end-use and the efficiency of central air conditioning systems are becoming an important issue for the European Commission and the National Authorities.

At present, the Energy Labelling Directive is restricted to household appliances. Indeed, the label is mandatory only for Room Air Conditioners with capacity equal to or lower than 12 kW. However, Eurovent established classification for full load Energy Efficiency Ratio of each type of chillers. The classification follows the A to G approach used in the European Energy Label for household appliances but the limits between classes have been defined for the existing chillers as listed in Eurovent directory, see Table1 for cooling mode.

Table 1: Chillers Energy Classification in Cooling Mode

EER Class	Air Cooled	Water cooled	Remote condenser
A	EER≥3.1	EER≥5.05	>=3,55
B	2,9≤ EER< 3,1	4,65≤ EER<5,05	3,4≤ EER<3,55
C	2,7≤ EER< 2,9	4,25≤ EER<4,65	3,25≤ EER<3,4
D	2,5≤ EER< 2,7	3,85≤ EER<4,25	3,1≤ EER<3,25
E	2,3≤ EER< 2,5	3,45≤ EER<3,85	2,95≤ EER<3,1
F	2,1≤ EER< 2,3	3,05≤ EER<3,45	2,8≤ EER<2,95
G	<2,1	<3,05	<2,8

The Energy Performance Building Directive requires calculation of building energy performance and regular inspection of central air conditioners and chillers with more than 12 kW cooling capacity. On the basis of this inspection, which shall include an assessment of the efficiency of the system and the sizing compared to the cooling requirements of the building, the competent authorities will ask the users to improve or replace the installed system by more efficient one. The transposition of this Directive in Member States shall oblige the National Authorities to develop policy measures for energy savings.
However, these measures only address the efficiency of the end-use equipment as determined under standard conditions at full load and will not realise many of the potential energy savings which are related to operating conditions at part load. To be really effective, energy efficiency options have to be defined not on the basis of nominal operating conditions but on a variety of part load conditions, which better reflect the central air conditioners operating modes that occur in real use. For this reason, Eurovent developed a European Seasonal Energy Efficiency Ratio, ESEER, index based on ARI approach to determine the Integrated Part Load Value, IPLV.
The manufacturers will provide their customers with a map of performance, not only at the four arbitrary percentages and temperatures. The customer can rely on ESEER computed from this map or compute its specific ESEER for its specific demand.
As there is no European or ISO standard for part load testing conditions, Eurovent standard, 6-C003-2006 has been amended including testing procedure for part load conditions.

The implementation of ESEER certification is scheduled for 2006 and the classification of chillers will be reviewed for translation into part load classes.

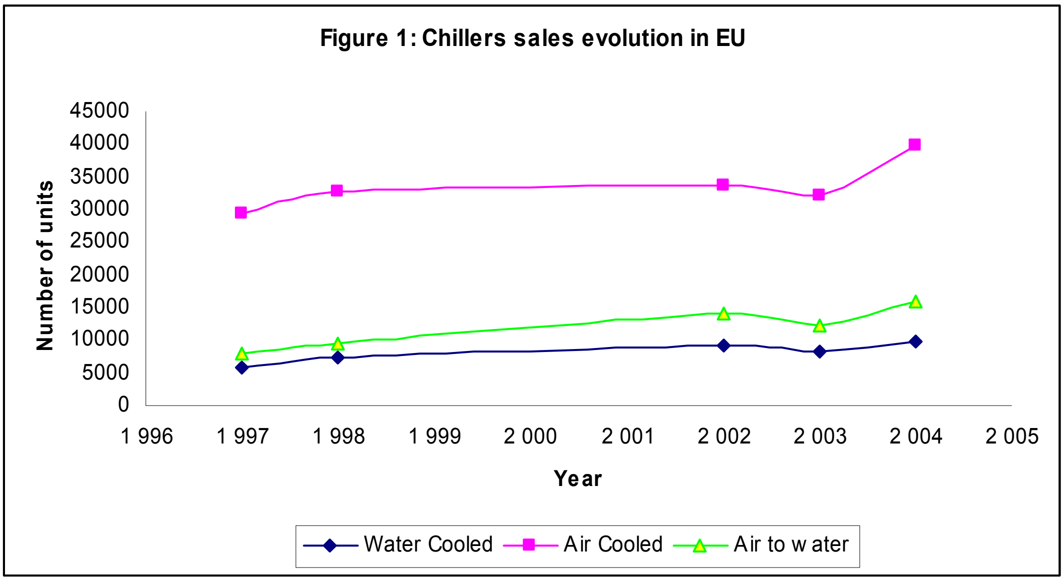


Figure 1: Energy Efficiency Classification Analysis

Starting with 1994, Eurovent is issuing a directory of certified products sold on the European market, giving information on certified performances.
At the beginning, the information was limited to cooling capacity and electrical power absorbed; then in 2002, it was extended to Energy Efficiency in cooling and heating mode. The last improvement was in 2005 with the publication of the classification of the chillers according to Table 1.
Using data published in the Eurovent directories since 2003 (2), we can see the evolution of EER for air cooled, Figure 2, and water cooled chillers, Figure 3.
Based on the standard test conditions, the mean EER for air cooled units is 2.56 while the average EER for water cooled units is 4.05. This difference is not inherent to chillers, but rather represents the temperature regime found in cooling towers. Nevertheless, water cooled systems are expensive because of the additional cost of using either a cooling tower or of accessing a natural water supply. Therefore, they are used only for large systems.

Figure 2: EER Evolution for Air Cooled Chillers

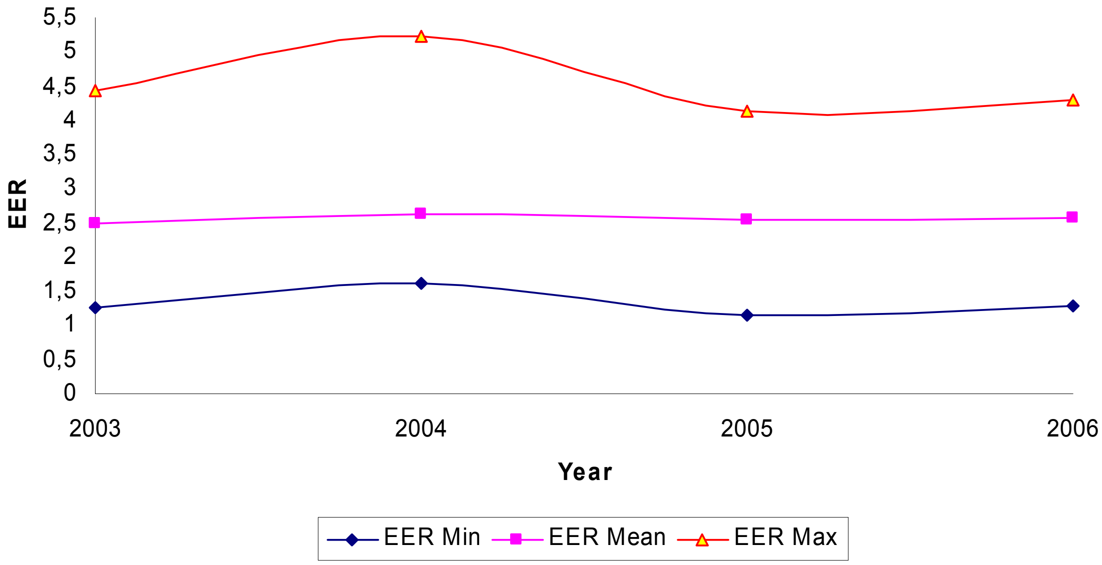
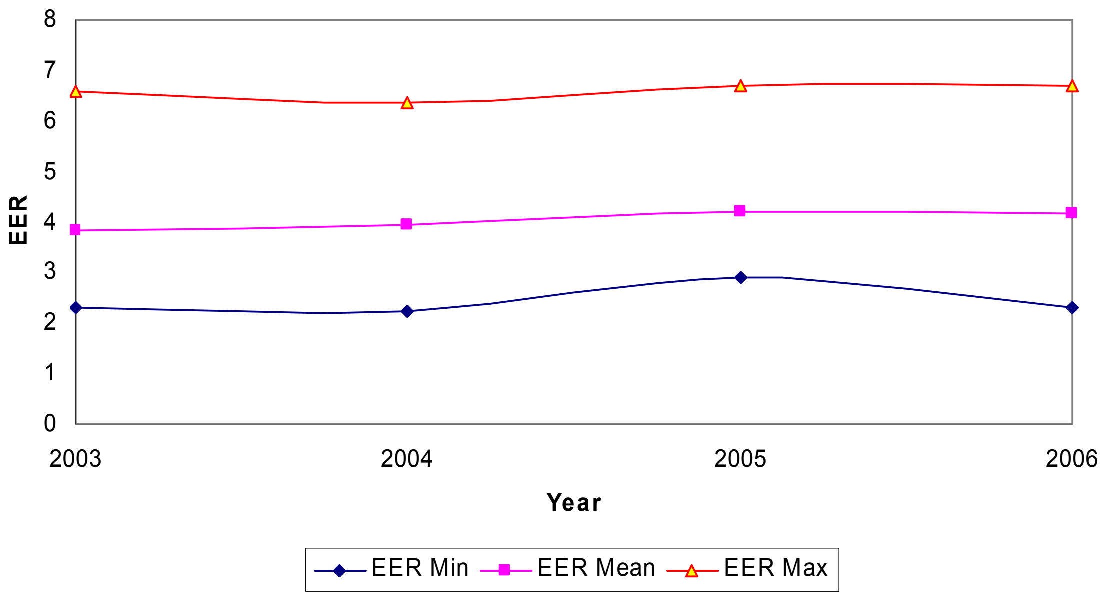


Figure 3:EER Evolution for Water Cooled Chillers



On voluntary basis, Eurovent implemented a classification according to energy efficiency. The purpose of this measure is double fold:

1. For high efficient chillers, the energy efficiency will be highlighted as the best units for each type being in Class A could be strongly promoted.
2. Minimum energy efficiency could easily be implemented, either on voluntary basis or decided by the European Commission.

The proposed classification is not ''labelling'', as no label will be used. Energy efficiency of chillers expressed by classes is indicated as ''Eurovent Class A'' or ''Eurovent Class B'' in manufacturers catalogues and Eurovent Directory of Certified products.

Based on existing chillers list published in Eurovent directory, limits between classes have been decided; see Table 1 for cooling mode, taken into account the following considerations:

1. Classification concerns gross EER at full load operation. When part load characteristics will be implemented, classes will be defined with equivalent ESEER.
2. To avoid confusion and possible use of classification by non-certified manufacturers, the designation ''Eurovent Class A'' or ''Eurovent Class B'' will be used and legally protected.
3. For ''low noise'' chillers, the class will correspond to full load operation with maximum fan speed. The same class will be used for lower fan speeds.

The classification has been implemented in February 2005; the distribution of number of units in each class is shown in Table 2

Table 2: Distribution of units in each class

Class/ kW	0-50	50-100	100-150	150-200	200-500	500-1000	>1000	Total
A	85	12	4	7	72	85	115	380
B	114	51	46	21	142	179	112	665
C	203	75	76	40	206	229	137	966
D	244	143	106	80	295	213	80	1161
E	383	131	121	84	432	246	98	1495
F	287	62	54	52	125	68	29	677
G	152	14	10	8	41	31	19	275
Total	1468	488	417	292	1313	1051	590	5619

It is too early to see the influence of this classification on energy efficiency. However, the distribution shows that 7% of certified chillers are in Eurovent Class A and in total only 5% of the certified chillers are in Eurovent Class G.

European Seasonal Energy Efficiency Ratio

Definition

Until now, the chillers are tested according to EN 14511 at full load conditions only while energy consumption is not covered by full load EER given in such a standard but by the average part load EER, often called Seasonal EER. This is largely used in the US market and called IPLV, Integrated Part Load Value.

The percentage of operating hours assigned to each part load condition in IPLV is corresponds to the US climate and buildings but could not be applied to the European ones. Eurovent established ESEER which represents the universe of EU buildings and climates.

The European Seasonal Energy Efficiency Ratio, ESEER, is a weighed formula enabling to take into account the variation of EER with the load rate and the variation of air or water inlet condenser temperature.
$ESEER = A.EER_A + B.EER_B + C.EER_C + D.EER_D$

With the following weighing coefficients:
A = 0.03
B = 0.33
C = 0.41
D = 0.23
For the following part-load ratings

Air cooled chillers:

Load Ratio (%)	Air temperature at condenser inlet (°C)
100	35
75	30
50	25
25	20

Water cooled chillers

Load Ratio (%)	water temperature at condenser inlet (°C)
100	30
75	26
50	22
25	18

ESEER Certification Procedure
ESEER enables to calculate the seasonal efficiency for all the European chillers. The constraint was to minimise the testing time while ensuring maximum precision. Contrary to ARI certification where one full load condition and three part load conditions are tested, in Eurovent certification, the ESEER procedure will be added to the existing one. That means, we will test one standard rating, one application rating selected by Eurovent and in addition one part load condition also selected by Eurovent. The manufacturer has to fill in Table 3 by giving first the number of stages of the chillers. Once notified, the table corresponding to the number of stages is built automatically. Then the manufacturer has to fill in the cooling capacity and absorbed electrical power for each condition and each stage.

ESEER procedure will calculate EER for each part load condition, and then compute ESEER value using the red cells shown in the Table 3. It also shows the intermediary points that have been calculated at 25, 50 and 75% load points in order to use the weighed coefficients derived for the ESEER.

Table 3: ESEER Calculation

Capacity stage number	4	Temperatures		FULL LOAD	STAGE 2	STAGE 3	STAGE 4
Cycling coefficient	0,9	35	Cooling Capacity	**153,7**	116,8	81,5	38,4
			Electrical Power	**60**	43,8	26,9	14,2
Weighting coefficients		30	Cooling Capacity	166,3	**126,4**	**88,1**	41,6
25 % - 50 % - 75 % - 100 %			Electrical Power	53,9	**39,4**	**24,2**	12,7
0.23 - 0.41 - 0.33 - 0 .03		25	Cooling Capacity	176,3	134,0	**93,4**	**42,9**
			Electrical Power	48,9	35,8	**22,0**	**11,9**
		20	Cooling Capacity	185,0	137,0	93,0	**50**

ESEER	3,87	**Electrical Power**	43,8	32,8	20,7	**10,9**
		Part load EER	**100%**	**75%**	**50%**	**25%**
			2,56	**3,29**	**4,11**	**4,45**

The default cycling coefficient proposed is 0.9, (3). A supplementary experimental work needs to be done to set the experimental testing conditions enabling the calculation of this coefficient from the manufacturer specifications of the minimum water loop volumes and of the smallest capacity step available.

Part load Testing Procedure:
The following rating conditions are used to test chillers at part load conditions:

- For air cooled chillers:
  1. The leaving water temperature is set at 7°C
  2. The evaporator water-flow rate is equal to the standard rating water-flow rate
  3. The air-flow rate is controlled by the chillers

- For water cooled chillers:
  1. The leaving water temperature is set at 7°C
  2. The evaporator water-flow rates are equal to the standard rating water-flow rates
  3. The condenser water flow rate is controlled by the chillers. If the chillers don't control it, the condenser water flow rate will be equal to the standard rating water flow rate.

For air cooled chillers, the condenser fan(s) should be operated by the control of the chillers. Whenever cycling of the condenser fan(s) occurs, the test should be led as follows:

- An acquisition time period of 1 hour is required.
- Tolerance on leaving water temperature can exceed the maximum permissible deviation.
- If cycles exceed 1 minute, an entire number of periods shall be acquired.

Conclusion

Eurovent has done and is still doing a lot for improving energy efficiency of HVAC products, all on a voluntary basis. This paper has presented the work in the field of chillers, namely certification of EER, classification of chillers and certification at part load conditions.
Next steps will be the elimination of Class G chillers (poorly efficient) and reviewing the classification of chillers according to ESEER instead of EER.

References:

(1):Energy Efficiency and Certification of Central Air Conditioners (EECCAC), Final report, April 2003. Co-ordinator: Jérôme ADNOT, assisted by Paul WAIDE
(2): Eurovent Directory 2003, 2004, 2005 and 2006
(3): Performances saisonnières des groupes de production d'eau glacée, PhD Thesis, presented at Ecole des Mines de Paris, May 2004 by Philippe RIVIERE

building
performance
congress

The U.S. Energy Policy Act of 2005 and Its Impact on Commercial Air Conditioning and Refrigeration Equipment

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Abstract
The U.S. Energy Policy Act of 2005 (EPACT 2005) establishes for the first time minimum federal energy efficiency standards for commercial refrigeration products and commercial ice makers. The Act also strengthens current federal standards for commercial air conditioning equipment with cooling capacities between 65,000 and 240,000 Btu/h (19 and 70 kW) and extends federal coverage to products up to 760,000 Btu/h (223 kW) of cooling capacity. This paper reviews these new minimum federal energy efficiency standards and analyzes their impact on products' design and cost. The role of the U.S. Department of Energy (DOE) in revising these standards in the future and in setting new energy efficiency standards on additional commercial products is also examined. Finally, an overview of tax incentives for very efficient commercial air conditioning products and for new energy efficient commercial buildings is provided.

Introduction
Energy efficiency standards for commercial and residential heating, ventilating and air conditioning (HVAC) products were first introduced in the U.S. back in 1975 as part of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 90 [1]. These standards were voluntary and covered unitary air conditioners, chillers, packaged terminal equipment and water-source heat pumps. In 1976, the state of California prescribed the first mandatory minimum efficiency standards. These standards applied to residential appliances such as refrigerators, freezers, room air conditioners and central air conditioners. Meanwhile at the federal level, the energy crisis of 1973 prompted the U.S. Congress to enact the Energy Policy Conservation Act (EPCA) of 1975 that directed the Federal Energy Administration to establish test procedures and voluntary energy efficiency improvement targets for certain home appliances [2]. In 1978, the National Energy Conservation Policy Act (NECPA) amended EPCA and directed the U.S. Department of Energy (DOE) to establish energy efficiency standards in replacement of EPCA voluntary targets [3]. NECPA also preempted all state energy efficiency standards prescribed after January 1, 1978. However, it is under the National Appliance Energy Conservation Act (NAECA) of 1987 and its amendments of 1988 that minimum federal energy efficiency standards were established for twelve categories of residential appliances including room air conditioners and central air conditioners and heat pumps [4].

On the other hand, commercial products received little attention until around 1992 when the Energy Policy Act (EPACT 1992) amended EPCA to establish a role for DOE to regulate energy efficiency standards for some fluorescent and incandescent reflector lamps, plumbing products, electric motors, commercial water heaters and commercial heating and cooling equipment [5]. Initial federal minimum efficiency standards for most commercial heating and cooling equipment were established in EPACT 1992 based on the requirements contained in ASHRAE Standard 90.1-1989 [6]. EPACT 1992 also established requirements to update these standards when they are amended by ASHRAE. These standards are believed to have saved a significant amount of energy in the U.S. Yet, several states were very active in the last two years to legislate mandatory minimum efficiency standards for commercial products not regulated under EPACT 1992, such as commercial refrigeration products, commercial ice makers and large commercial unitary air conditioners with cooling capacities above 240,000 Btu/h (70 kW).

These state activities prompted the Air-Conditioning and Refrigeration Institute (ARI), representing the air conditioning and refrigeration industry, and the American Council for an Energy Efficient Economy (ACEEE), representing several energy efficiency groups, to reach agreements on consensus minimum federal energy efficiency standards for commercial refrigerators, freezers, and refrigerator/freezers; commercial ice makers; and commercial air conditioners. These agreements were recommended for potential inclusion in the energy efficiency legislation being developed. In late July 2005, both houses of the U.S. Congress passed a new federal energy legislation which included the consensus agreements. In August 2005, the Energy Policy Act of 2005 was signed into law [7].

This paper reviews the minimum federal energy efficiency standards for commercial refrigeration products, commercial ice makers, and commercial air conditioners enacted into law by EPACT 2005. The role of the U.S. DOE in revising these standards in the future and in setting new energy efficiency standards on additional commercial products is examined. This paper also reviews tax incentives on commercial air conditioning products and commercial buildings.

Federal Minimum Energy Efficiency Standards

EPACT 2005 strengthens current federal minimum energy efficiency standards for air-cooled commercial air conditioning equipment with cooling capacities between 65,000 and 240,000 Btu/h (19 to 70 kW) and extends federal coverage to products up to 760,000 Btu/h (223 kW) of cooling capacity. The act also establishes for the first time minimum energy efficiency standards for commercial refrigeration products and commercial automatic ice makers.

Commercial Air Conditioning Equipment

Federal minimum energy efficiency standards for air-cooled commercial air conditioning and heat pump equipment were first established in 1992 under EPACT and covered equipment up to 240,000 Btu/h (70 kW) of cooling capacity. The efficiency standards were at the levels specified in ASHRAE 90.1-1989. In addition to energy conservation standards, EPACT provided for definitions and test procedures. Furthermore, EPACT requires when the efficiency levels in ASHRAE 90.1 are amended, that DOE establishes an amended national standard at the level specified in the amended ASHRAE 90.1 standard, unless DOE determines, through a rulemaking supported by clear and convincing evidence, that a more stringent standard in technologically feasible and economically justified and would result in significant additional energy conservation.

In the nineties, ASHRAE 90.1 went through an extensive revision process, which culminated with the release in the fall of 1999 of ASHRAE 90.1-1999 [8]. After conducting a series of economic and technical analyses, ASHRAE increased the energy efficiency levels of all HVAC equipment over the levels listed in ASHRAE 90.1-1989, at the exception of the 3-phase unitary air conditioners and heat pumps less than 65,000 Btu/h, for which ASHRAE opted to wait until DOE finalizes its rulemaking on residential single-phase unitary products[1]. Based on the requirements of EPACT, the revisions to the energy efficiency levels in ASHRAE 90.1-1999 triggered a rulemaking at DOE to amend the federal minimum efficiency standards. In 2001, DOE published a final rule, adopting the ASHRAE 90.1-1999 efficiency levels as federal minimum efficiency standards for most but not all EPACT-covered HVAC equipment [9]. Among the products for which new minimum federal standards were not adopted were air-cooled commercial unitary air conditioners and heat pumps with cooling capacities between 65,000 and 240,000 Btu/h. For these products, DOE concluded that cost-effective energy savings could result from more stringent standards and decided to undertake further analyses to assess if higher efficiency levels could be justified.

DOE started a rulemaking process in 2001 and published an Advanced Notice of Proposed Rulemaking (ANOPR) in 2004 to solicit public comments on its preliminary technical analyses [10].

[1] The ASHRAE 90.1-1989 efficiency levels for the 3-phase air-cooled unitary air conditioners and heat pumps less than 65,000 Btu/h are identical to the federal minimum efficiency standards of the residential single-phase unitary products established by the National Appliance Energy Conservation Act (NAECA). DOE amended the NAECA standards in 2001 and ASHRAE 90.1 proposed similar efficiencies for 3-phase products through the release for public review of addendum f to ASHRAE 90.1-2004. The addendum received no public comments and is expected to be published in March or April 2006.

Under normal procedures, DOE was expected to finalize the rule in 2007 or 2008. However, the enactment of EPACT 2005 officially ended to the rulemaking process. In addition, EPACT 2005 extended federal coverage to air-cooled air conditioners and heat pumps with cooling capacities between 240,000 and 760,000 Btu/h (70 and 223 kW). In October 2005, DOE published a technical amendment codifying the legislated standards into the U.S. code of federal regulations [11].

The minimum federal energy efficiency standards enacted by EPACT 2005 will become effective on January 1, 2010. This effective date is designed to coincide with the phase out date of HCFC-22 mandated by the U.S. Clean Air Act [12]. Table 1 summarizes the current and future minimum federal energy efficiency standards for air-cooled commercial air conditioners and heat pumps with cooling capacities between 65,000 and 760,000 Btu/h (19 and 223 kW). As can be seen, the future federal standards are a significant improvement over current standards – as much as 29% better in the case of air conditioners between 135,000 and 240,000 Btu/h (19 and 40 kW) of cooling capacity. These new standards will result in over 2.1 quads (2.2×10^{18} Joules) of cumulative primary energy savings by year 2035 [13].

Table 1: Current and Future Minimum Federal Energy Efficiency Standards for Air-Cooled Air Conditioners and Heat Pumps

Cooling Capacity In Btu/h x10^3 (kW)	**Current Federal Standards (EPACT 1992)**		**Future Federal Standards (EPACT 2005) 1/1/2010**	
	Air Conditioners	**Heat Pumps**	**Air Conditioners**	**Heat Pumps**
≥ 65 and < 135 (≥19 and <40)	8.9 EER	8.9 EER 3.0 COP	11.2 EER	11.0 EER 3.3 COP
≥ 135 and < 240 (≥40 and <70)	8.5 EER	8.5 EER 2.9 COP	11.0 EER	10.6 EER 3.2 COP
≥ 240 and < 760 (≥70 and <223)	N/A	N/A	10.0 EER	9.5 EER 3.2 COP

The stringency of the future federal standards is further illustrated in Figures 2 and 3 where the energy efficiency ratio (EER) of commercial air conditioners currently manufactured in the U.S. is plotted against the future minimum standards. The data used to generate the figures was taken out of the ARI directory of certified unitary large equipment [14]. As can be seen from the figures, the vast majority of commercial air conditioners currently sold in the U.S. do not meet the future standards. In fact, as much as 89% of air conditioner models between 65,000 and 135,000 Btu/h of cooling capacity, and close to 84% of air conditioner models with cooling capacities between 135,000 and 240,000 Btu/h have energy efficiency ratios below the future standards. Meeting these new federal standards will require significant equipment redesign and factory retooling. The cost to industry to redesign entire product lines and retool factories will be considerable and is expected to be over $200 million.

The cost of the equipment at the future federal standards is expected to be considerably higher. Figure 3 shows the installed cost of a 90,000 Btu/h and 180,000 Btu/h air conditioners as a function of EER. The data used to generate the figure was taken from the analysis conducted by DOE during the rulemaking process on commercial air conditioners [13]. According to the figure, the cost of commercial air conditioners at the new federal standards will be on average 20% higher than equipment at the current federal standards. It should be noted that the cost figures derived by DOE are believed to be conservative and that the actual cost will likely be higher.

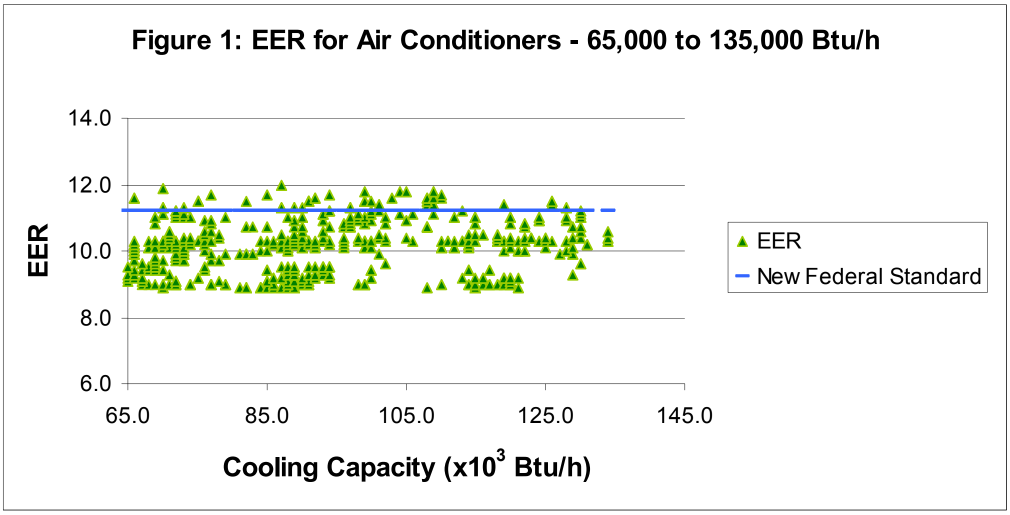
Figure 1: EER for Air Conditioners - 65,000 to 135,000 Btu/h
14.0
12.0
10.0
8.0
6.0
EER
65.0
85.0
105.0
125.0
145.0
Cooling Capacity (x10³ Btu/h)
EER
New Federal Standard

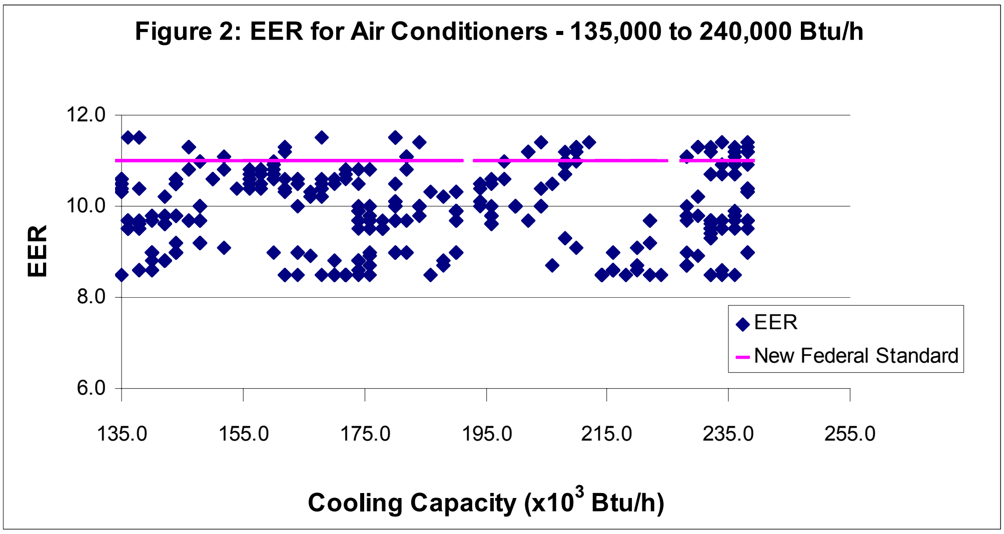
Figure 2: EER for Air Conditioners - 135,000 to 240,000 Btu/h
12.0
10.0
8.0
6.0
EER
135.0
155.0
175.0
195.0
215.0
235.0
255.0
Cooling Capacity (x10³ Btu/h)
EER
New Federal Standard

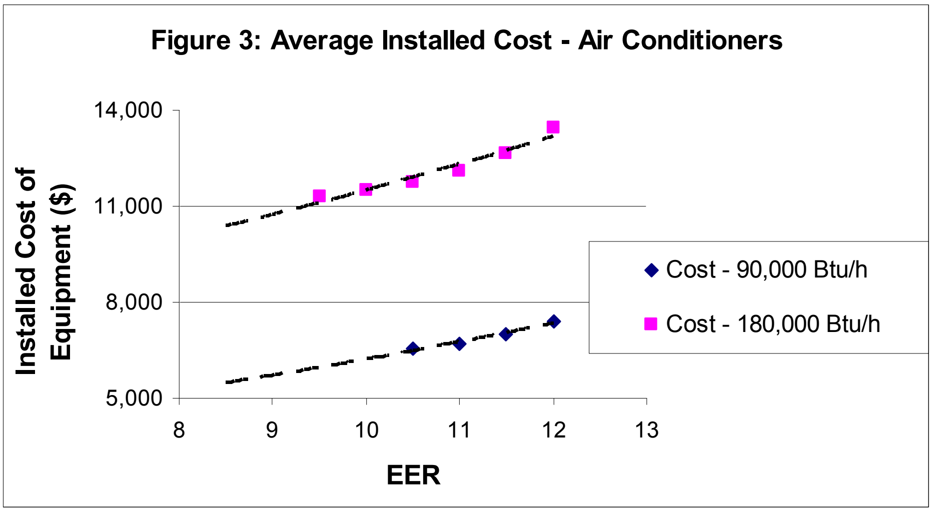
Figure 3: Average Installed Cost - Air Conditioners
14,000
11,000
8,000
5,000
Installed Cost of Equipment ($)
8
9
10
11
12
13
EER
Cost - 90,000 Btu/h
Cost - 180,000 Btu/h

Commercial Refrigeration Products

Until recently, the energy consumption of commercial refrigeration products was unregulated in the U.S. However, the situation changed in 2002, when the state of California, through the California Energy Commission (CEC) mandated minimum energy efficiency standards for commercial refrigerators, freezers, and refrigerator/freezers [15]. The standards impacted commercial self-contained reach-ins refrigerators and freezers with transparent and solid doors. Two tiers of energy efficiency standards were established, with the first effective in March 2003 and the second, more stringent tier effective in August 2004. In late 2004, California amended its regulations and adopted two additional tiers of energy consumption [16]. Tier 3 became effective on January 1, 2006, while tier 4 will become effective on January 1, 2007. On average, these new efficiencies are 15 to 30% more stringent than tier 2. Following the steps of California, other states introduced legislations to regulate the energy consumption of self-contained commercial refrigeration products. Many of these proposed legislations failed to be enacted, but three states, Connecticut, Maryland and Washington were successful in legislating state standards. Connecticut and Maryland adopted the California tier 2 standards, while Washington adopted the California tier 3 and tier 4 levels. The state standard activities prompted ARI and ACEEE to reach a consensus agreement on minimum federal energy efficiency standards which was adopted in EPACT 2005. In addition to setting minimum efficiency standards, EPACT 2005 also specified ASHRAE 117 as the federal test procedures for these products and rating temperatures of 38°F (3.3°C) and 0°F (-17.8°C) for refrigerators and freezers respectively [17]. However, provisions were added to the legislation directing DOE to review any new test procedures (besides ASHRAE 117) approved by the American National Standards Institute for possible adoption as the federal test procedure. These provisions were added to allow industry standards such as ARI 1200, which includes rating conditions, to be considered as the new federal test procedure in lieu of ASHRAE 117 [18].

Table 2 summarizes the new federal standards for self-contained commercial refrigeration products. These standards, which will become effective on January 1, 2010, are similar to the California tier 4 standards. Based on estimates from the Department of Energy, these standards will save approximately 0.59 quads (0.62 x 10^{18} Joules) of primary energy by year 2035 [19]. These federal standards are also plotted in Figures 4 through 6 against the energy consumption of refrigerators, freezers and refrigerator/freezers listed in the CEC database. The figures indicate that the standards are particularly stringent for reach-ins refrigerator and freezers with transparent doors. On average, 50% of the refrigerators with transparent doors, and more than 70% of the freezers with transparent doors do not meet the future federal standards. Similarly, close to 70% of the refrigerator/freezers consume more energy than the federal standard. On the other hand, a large percentage of refrigerators and freezers with solid doors meet or exceed the future federal minimum standards. However, it should be pointed out that the limited number of reach-ins listed in the CEC database are believed to be among the most efficient reach-ins currently available in the U.S. market, and that the actual percentage of models currently not meeting the future federal standards is significantly higher.

Table 2: Minimum Federal Energy Efficiency Standards for Self-Contained Commercial Refrigeration Products (Effective January 1, 2010)

Self-Contained Commercial Refrigeration Product	Door Type	Federal Energy Efficiency Standards – Effective 1/1/2010 (Maximum energy Consumption in kWh/day)
Refrigerators	Solid	0.10 V+2.04
	Transparent	0.124 V+3.34
Freezers	Solid	0.40 V+1.38
	Transparent	0.75 V+ 4.1
Refrigerator/Freezers	Solid	0.27 AV – 0.71 or 0.70 (which ever is greater)
Refrigerator for pull down application	Transparent	0.126 V + 3.51
V= Refrigerator or freezer compartment volume (ft^3) AV= Adjusted volume (ft^3) defined as [1.63 x freezer compartment volume (ft^3)] + refrigerator compartment volume (ft^3)]		

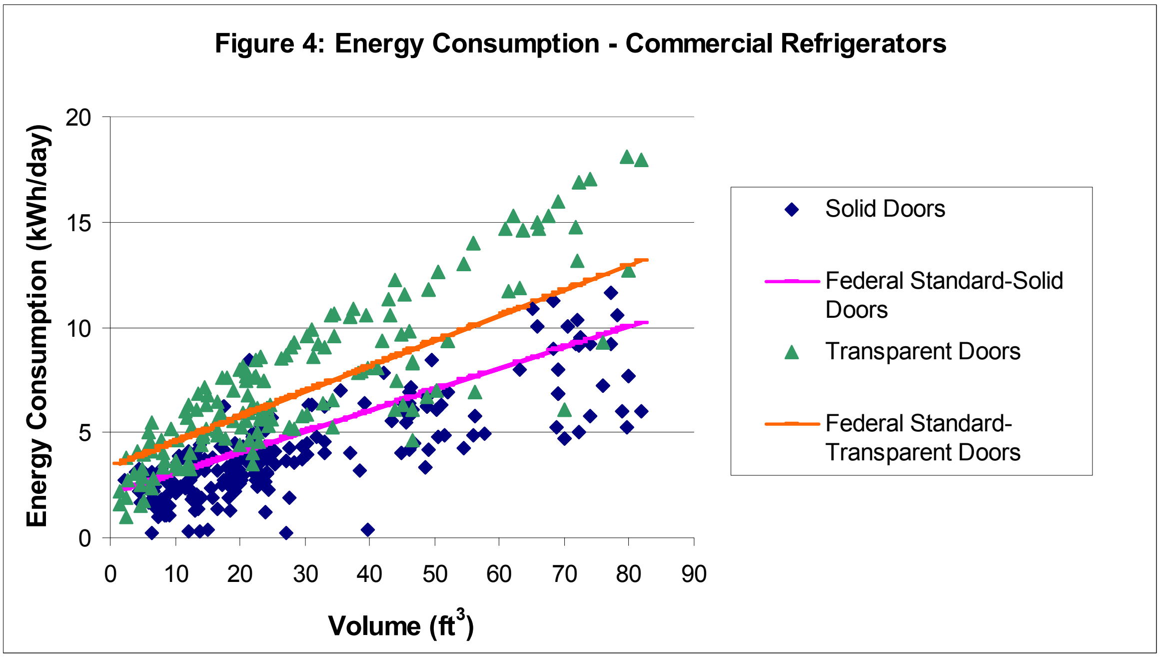

Figure 7 shows the cost of self-contained refrigerators and freezers as a function of the energy consumption. The figure is based on limited data collected during the rulemaking process in California [20]. As expected, the cost increases as the equipment becomes more efficient. According to the figure, the cost of self-contained refrigerators and freezers at the future federal standard will on average be over 30% more expensive than baseline units.

In addition to putting an end to a patchwork of state standards, the EPACT 2005 legislation also directs the Department of Energy to determine by January 1, 2013 if the standards for self-contained commercial refrigeration products need to be amended. Further, the legislation directs DOE to prescribe, by rule, standard levels for ice-cream freezers; self-contained commercial refrigerators, freezers, and refrigerator-freezers without doors; and remote condensing commercial refrigerators, freezers, and refrigerator-freezers, by January 1, 2009, with the standard levels effective for equipment manufactured on or after January 1, 2012. These standards are expected to save an additional 0.83 quads (0.87 x 10^{18} Joules) of primary energy by year 2035 [21].

Commercial Ice Makers

As with commercial refrigeration products, the energy consumption of automatic commercial ice makers was unregulated in the U.S. until the state of California, through the CEC, amended its appliance efficiency standard – Title 20 in late 2004 to require minimum efficiency levels [16]. The standards adopted in California, which will become effective on January 1, 2008, apply to ice cube machines with harvest rates between 50 lbs (22.7 kg) and 2500 lbs (1134 kg) of ice per 24 hours of operation when tested at ARI standard 810 rating conditions [22]. The adoption of new standards in California prompted other states to introduce legislations to regulate the energy consumption of commercial ice makers. However, at the exception of the state of Washington which adopted similar standards than California with the same effective date, the other states were not successful in regulating the products. Nevertheless, the prospect of continued state standards activities in the near future prompted ARI and ACEEE to reach a consensus agreement on minimum federal energy efficiency standards. The consensus agreement was later adopted in EPACT 2005 and put an end to the proliferation of state standards. The minimum federal standards, which are based on the California standards, are summarized in Table 3. These standards will become effective on January 1, 2010.

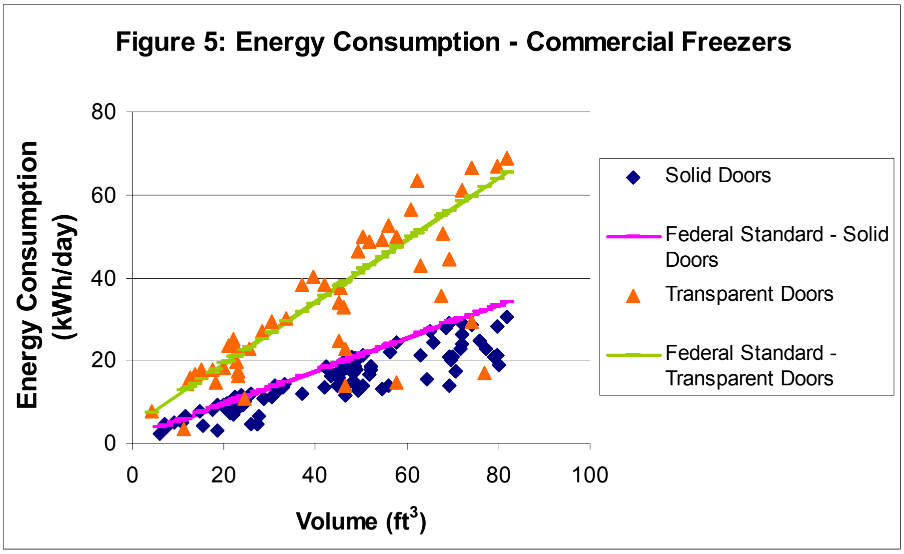
Figure 5: Energy Consumption - Commercial Freezers
Energy Consumption (kWh/day)
0
20
40
60
80
0
20
40
60
80
100
Volume (ft3)
Solid Doors
Federal Standard - Solid Doors
Transparent Doors
Federal Standard - Transparent Doors

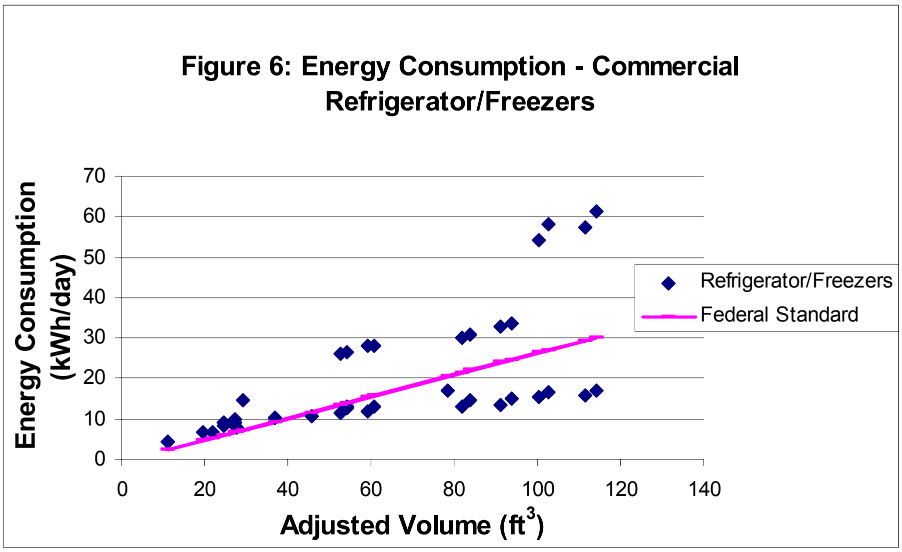
Figure 6: Energy Consumption - Commercial Refrigerator/Freezers
Energy Consumption (kWh/day)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
Adjusted Volume (ft3)
Refrigerator/Freezers
Federal Standard

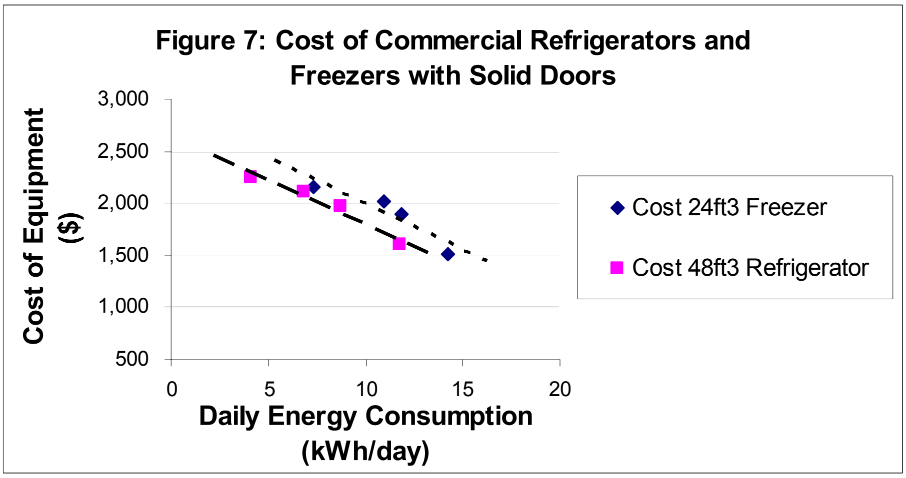
Figure 7: Cost of Commercial Refrigerators and Freezers with Solid Doors
Cost of Equipment ($)
500
1,000
1,500
2,000
2,500
3,000
0
5
10
15
20
Daily Energy Consumption (kWh/day)
Cost 24ft3 Freezer
Cost 48ft3 Refrigerator

Table 3: Minimum Federal Standards for Commercial Ice Makers (Effective January 1, 2010)

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hours)	Maximum Energy Use (kWh/100 lbs Ice)	Maximum Condenser Water Use (gal/100 lbs Ice)
Ice Making Head	Water	<500	7.80-0.0055H	200-0.022H
		≥500 and <1436	5.58-0.0011H	200-0.022H
		≥1436	4.0	200-0.022H
Ice Making Head	Air	<450	10.26-0.0086H	Not Applicable
		≥450	6.89-0.0011H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1000	8.85-0.0038H	Not Applicable
		≥1000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038H	Not Applicable
		≥934	5.3	Not Applicable
Self-Contained	Water	<200	11.40-0.019H	191-0.0315H
		≥200	7.60	191-0.0315H
Self-Contained	Air	<175	18.0-0.0469H	Not Applicable
		≥175	9.80	Not Applicable
H= Harvest rate in pounds per 24 hours. Water use is for the condenser only and does not include potable water used to make ice.				

In addition to setting maximum energy consumption and condenser water use, EPACT 2005 also established ARI standard 810 as the federal test procedure. Furthermore, EPACT 2005 directs the Department of Energy to publish a final rule no later than January 1, 2015 to determine if it is technologically feasible and economically justified to amend the standards listed in Table 3.

The energy consumption of various types of commercial ice makers is plotted against the federal standards in Figures 8, 9 and 10. The data on energy consumption was taken from the ARI directory of certified commercial ice makers. The figures show that the federal standards are particularly stringent. Close to 50% of the self-contained ice makers made today do not meet the federal standards. For remote condensing units and ice making heads, the percentage of units not meeting the federal standard is around 60%. According to the Department of Energy, these federal standards will save an estimated 0.16 quads (0.17 x 10^{18} Joules) of primary energy by year 2035 [19].

Cost figures for commercial ice makers at the federal standards are sketchy. Limited analyses done by ACEEE for the California Energy Commission show that commercial ice makers at the federal standards will cost about 4% more than baseline units [20]. However, the real incremental cost will likely be significantly higher.

Tax Incentives

EPACT 2005 contains a variety of conservation and energy efficiency tax incentives for businesses and consumers ranging from tax credits for new homes and appliances (including air conditioners and heat pumps) to tax deductions for commercial buildings. Table 4 summarizes the tax credits and the energy efficiency levels for air conditioners and heat pumps. The $300 tax credit applies to equipment placed in service from January 1, 2006 to December 31, 2007. Cumulative energy savings through year 2020 from these tax credits are estimated at 0.45 quads (0.47 x 10^{18} Joules) [23].

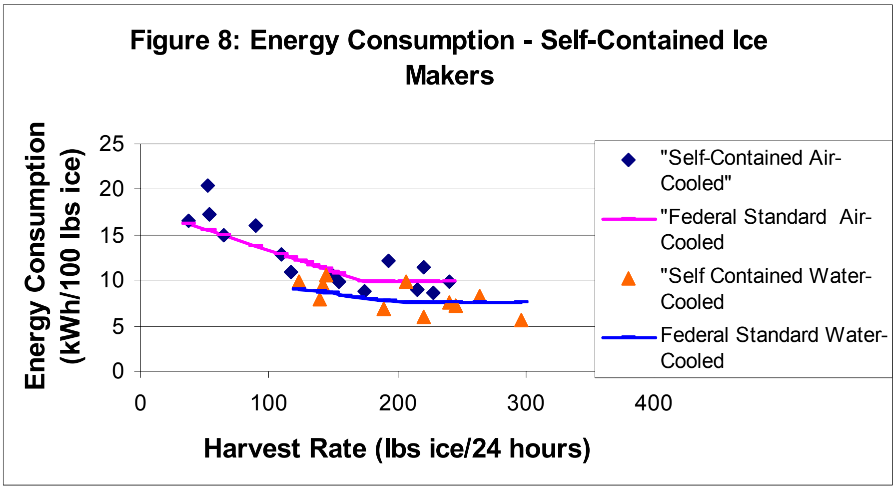
Figure 8: Energy Consumption - Self-Contained Ice Makers
Energy Consumption (kWh/100 lbs ice)
25
20
15
10
5
0
0
100
200
300
400
Harvest Rate (lbs ice/24 hours)
"Self-Contained Air-Cooled"
"Federal Standard Air-Cooled
"Self Contained Water-Cooled
Federal Standard Water-Cooled

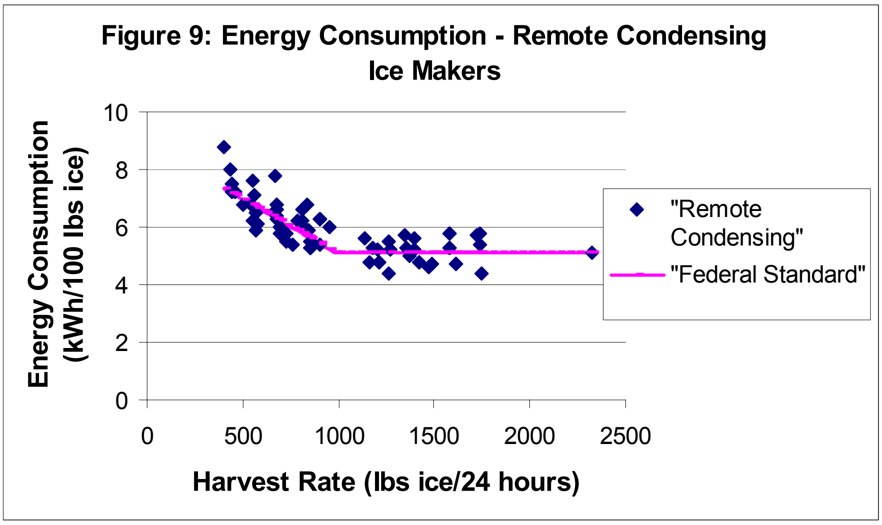
Figure 9: Energy Consumption - Remote Condensing Ice Makers
Energy Consumption (kWh/100 lbs ice)
10
8
6
4
2
0
0
500
1000
1500
2000
2500
Harvest Rate (lbs ice/24 hours)
"Remote Condensing"
"Federal Standard"

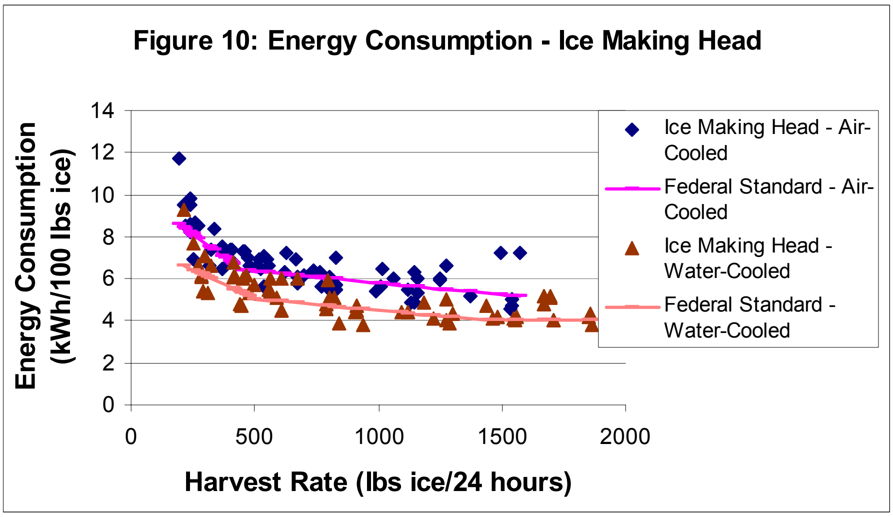
Figure 10: Energy Consumption - Ice Making Head
Energy Consumption (kWh/100 lbs ice)
14
12
10
8
6
4
2
0
0
500
1000
1500
2000
Harvest Rate (lbs ice/24 hours)
Ice Making Head - Air-Cooled
Federal Standard - Air-Cooled
Ice Making Head - Water-Cooled
Federal Standard - Water-Cooled

Table 4: Tax Credit for Air Conditioners and Heat Pumps

Equipment Type	Minimum Efficiency	Tax Credit
Central Air Conditioners	15 SEER, 12.5 EER	$300
Central Air Source Heat Pumps	15 SEER, 13 EER, 9 HSPF	$300
Ground Source Heat Pumps		
Closed Loop	14.1 EER, 3.3 COP	$300
Open Loop	16.2 EER, 3.6 COP	$300
Direct Expansion (DX)	15 EER, 3.5 COP	$300

EPACT 2005 also provides a tax deduction of up to $1.80 per square foot for new commercial buildings that are certified to reduce energy use by 50% relative to the requirements of ASHRAE standard 90.1-2001. In addition, the legislation allows for a partial tax deduction of $0.60 per square foot for improvements in (1) interior lighting, or (2) HVAC and hot water systems, or (3) building envelope systems. These provisions are effective for property placed in service from January 1, 2006 through December 31, 2007. The Treasury Department, after consultation with DOE, will issue regulations describing the energy-saving targets for each type of system covered (interior lighting, HVAC/hot water, building envelope) and the methods for calculating and verifying energy consumption. This provision is expected to save an additional 0.29 quads (0.3 x 10^{18} Joules) of primary energy by year 2020 [23].

Conclusions

The Energy Policy Act of 2005 is the first major effort of the U.S. government to address energy policy since the Energy Policy Act of 1992. The legislation contains two significant energy efficiency provisions: (1) new minimum federal energy efficiency standards for 16 products, and (2) tax incentives for several types of energy-saving measures and technologies. Among the new federal minimum energy efficiency standards contained in EPACT 2005 are three historic consensus agreements negotiated by the Air-Conditioning and Refrigeration Institute (ARI) representing the air conditioning and refrigeration industry, and the American Council for an Energy-Efficient Economy (ACEEE) representing several energy efficiency groups. These agreements, enacted into law through EPACT 2005, establish for the first time minimum federal energy efficiency standards for commercial refrigeration products and commercial ice makers. The Act also strengthens current federal standards for commercial air conditioning equipment with cooling capacities between 65,000 and 240,000 Btu/h (19 and 70 kW) and extends federal coverage to products up to 760,000 Btu/h (223 kW) of cooling capacity. These new federal minimum efficiency standards, effective January 1, 2010, will save an estimated 3.68 quads (3.9 x 10^{18} Joules) of primary energy by year 2035. In addition to being beneficial to the environment and consumers, EPACT 2005 gives manufacturers regulatory certainty to develop new models by year 2010 that will comply with both the new federal minimum energy efficiency standards and the phase out date of hydrochlorofluorocarbon refrigerants mandated by the U.S. Clean Air Act.

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building
performance
congress

Experimentation of the CEN standard on inspection of air-conditioning systems

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Abstract

The paper presents the first results of few "simulations" of inspection on real air-conditioning installations. The aim of the on-site testing is to check the feasibility, the efficiency and to determine the blanks of procedures proposed by the CEN standard. It is however only a small part of a larger study aiming to define best practices for inspecting and auditing of air-conditioning systems. Especially, that paper discusses of several topics: how long is the procedure for a whole building? What can an inspector conclude about the performances of the installation by applying the standard in that state? Is the incentive strong enough to encourage building owners to improve or replace their equipments? Using conclusions of that first experiment, the paper will suggest some improvements of the original checklist by detailing possible measurements that should be made in order to conclude more precisely on both sizing and efficiency.

Introduction

The regular inspection of air-conditioning systems became compulsory with the energy performance of buildings directive (EPBD). Although most member-states agree with the helpfulness of such an inspection in order to evaluate performances and to advice building owners on how to make improvements, the consensus about the content of the procedure is difficult to reach. A CEN (European Committee for Standardization) standard, shortly presented by the paper, partially gave answers by proposing a common basis. First critics are that the framework is lacking of flexibility, the scope is far too large, the procedure is fuzzy and then potential savings are low. In order to check the feasibility of the inspection, the CEN standard has been on-site tested on several technical installations.

There is no doubt the CEN standard is a good common basis. Several difficulties however remain with its applicability in that state especially for the assessment of both sizing and efficiency. Starting from the test conclusions, several improvements will be brought. The problem is then to have quantitative measurements cohabited with qualitative observations in order that inspectors are able to assess sizing and performances as objectively as possible while minimizing the time spent.

The development of more exhaustive checklists seems not sufficient to reach both objectivity and homogeneity in assessments. In that state, the standard lets a wide range of interpretations especially about the necessary actions that building owners will have to take after an inspection. Therefore, further developments at the European level are crucial in order that the regular inspection becomes a real incentive for building owners to invest in improvements or replacements.

The EPBD Article 9 makes regular inspection compulsory

Definitions

The EPBD (EP 2003) defines an air-conditioning system as “a combination of all components required to provide a form of air treatment in which temperature is controlled or can be lowered, possibly in combination with the control of ventilation, humidity, and air cleanliness”. Moreover, “the effective rated output (kilowatt) is the maximum calorific output specified and guaranteed by the manufacturer as being deliverable during continuous operation while complying with the useful efficiency indicated by the manufacturer”.

The EPBD Article 9, named “inspection of air-conditioning systems”, stipulates that “with regard to reducing energy consumption and limiting carbon dioxide emissions, Member States shall lay down the necessary measures to establish a regular inspection of air-conditioning systems of an effective rated output of more than 12 kilowatts”. Moreover, “this inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building”. Finally, “appropriate advice shall be provided to the users on possible improvement or replacement of the air conditioning system and on alternative solutions”.

The CEN Standard for the transposition of the EPBD article 9

Concerning the article 9 issue, the European Commission requested CEN to develop a standard (CEN 2004) defining the guidelines for inspection of air-conditioning systems in order to accelerate the transposition and to homogenize national laws on that topic. The CEN philosophy was only to impose a minimal standard acceptable by every Member States. But it has been done to the detriment of the energy savings because almost only qualitative observations of operation and maintenance (O&M) were demanded. In order to compensate the lack of quantitative performance measurements and then to increase potential energy savings, the scope of article 9 was widened to its maximum. Thus, cooling equipments (reversible or not), water and air distribution, air-exhaust systems and the control system are included. Only, mechanical ventilation (without mechanical cooling) and heating only systems are excluded. Moreover, although several translations were possible for the 12-kilowatt limit of the article 9 (DUPONT 2005), the CEN chose the maximizing way: a building must be inspected when the sum of individual rated cooling capacities of each installed air-conditioners is higher than 12 kilowatts.

The inspected air-conditioning installations

What can an inspector conclude on the energy performances of an existing air-conditioning system by applying the CEN standard? That question was the basis of our study. We inspected (table 1) real systems in order to know about the feasibility and the efficiency of the CEN proposed solution. Our ambition was not to make a statistical study. The four inspected buildings are obviously not representative of the whole French and even European stock and then general observations we would make would not be the reflection of practices in force. Starting from our observations and taking into account the feasibility of some measurements and the time spent on site, we developed a simple procedure based on checklists that could be applicable by inspectors. Every method proposed is then deduced from both our experiment and inspection constraints (duration, feasibility, costs etc…).

The regular inspection of air-conditioning systems was developed in order to incite building owners to invest in improvements or even a whole replacement by proving them there are potential savings to achieve. But before any investment, buildings must be audited in order to determine which improvements are cost-effective. The objectives of the project, from which that paper is extracted, are to propose best practices for inspecting and auditing air-conditioning installations. The checklist-based structure of our method is then the same for these two levels of investigation. Only the time spent, metrology and tools used are different from inspection to audit.

Table 1: summary of the inspected buildings and systems

Owner	Location	Building	Zone	System	Control
Ecole des Mines de Paris	Paris, France	17th century Education Only few lecture rooms or offices are air-conditioned	415m^2 lecture room 310 occupants maximum Air-conditioned since 1985	64kW split-system 2-power levels Water-cooled Non-recycled water DX-AHU constant flow Heat-recovery	Thermostat Occupancy sensor for chiller Programmer for AHU
			150m^2 lecture room 130 occupants maximum Air-conditioned since 1997	29,7kW rooftop Constant flow Air-cooled Reversible (not used)	Timer Thermostat
			120m^2 lecture room 115 occupants maximum Air-conditioned since 1972	17,5kW packaged-unit Water-cooled Non-recycled water Constant flow Ducted Reversible (not used) Natural ventilation	Thermostat
Orpea	Agen, France	Built in 2001 Retirement home 3800m^2	3400m^2 treated areas 85 bedrooms Restaurant Living-room	8 VRF units (207kW) Air-cooled Reversible Mechanical ventilation Installation in 2001	BEMS
EDF	Moret-sur-Loing, France	Built in 1970 Restaurant	200 occupants maximum 400 meals/day Air-conditioned since 1970	80kW chiller 3-power levels Water-cooled Dry-cooler AHU constant flow 100% fresh air Extraction through kitchen hoods Storage	Supply temperature depends on outside temperature No time control
		Built in 1973 Offices	1140m^2 offices and meeting rooms 42 occupants Air-conditioned since 1993	197kW chiller 4-power levels Air-cooled AHU constant flow 34 FCU	One thermostat per FCU No time control

The development of our checklists

Necessary points to check

The EPBD article 9 only demands an assessment of both sizing and efficiency. However, that global performance assessment must not focus only on the air-conditioning system but also on everything that interacts with it. Like energy audits, it is better for the inspection to consider a whole system {building; equipments; occupants} because each component influences energy consumptions. Our idea was to develop checklists as exhaustive as possible so that an inspector can compare “bad” and “good” points in order to mark any air-conditioning installation. That is why our checklists were built to find any problem both in the design and during the every day operation. Necessary items to check are (figure 1):

Cooling needs
The system efficiency is not only due to the efficiency of each individual equipment. The whole system defined above would not be called “efficient” without an optimization of the cooling needs. Indeed, the building design (solar protections, thermal insulation and inertia, air infiltrations) and internal loads (occupancy, air renewal rate, artificial lighting, electrical appliances) have huge consequences on energy consumptions of air-conditioning systems. The way they are optimized must be a part of the inspection. Indeed, too many systems are simply improved or replaced without any previous load reduction that would have however led to much greater energy savings.

Individual efficiency of technical equipments
The second way to get the best efficiency is to correctly design and size networks and equipments. The effective rated output of cold generating systems and motors must fit to real needs. Indeed, part load operation is often (depending on the type of equipment and the load itself) less efficient than full load operation.

The choice of energy efficient equipments is not a sufficient condition but remains necessary to reach high levels of performance. Cold generating systems are only one part of the problem and energy efficiency must obviously be extended to auxiliaries. Indeed, in industry and tertiary sectors, the average motor load factor was estimated between 40% and 50% depending on the power (EC 2000). In addition, fans and pumps often operate for much longer periods than cooling systems so that auxiliaries can take part to 50% of annual energy consumptions (EECCAC 2003) for chiller based systems especially. That is why high attention must be paid on sizing methods and technology choices during the inspection procedure.

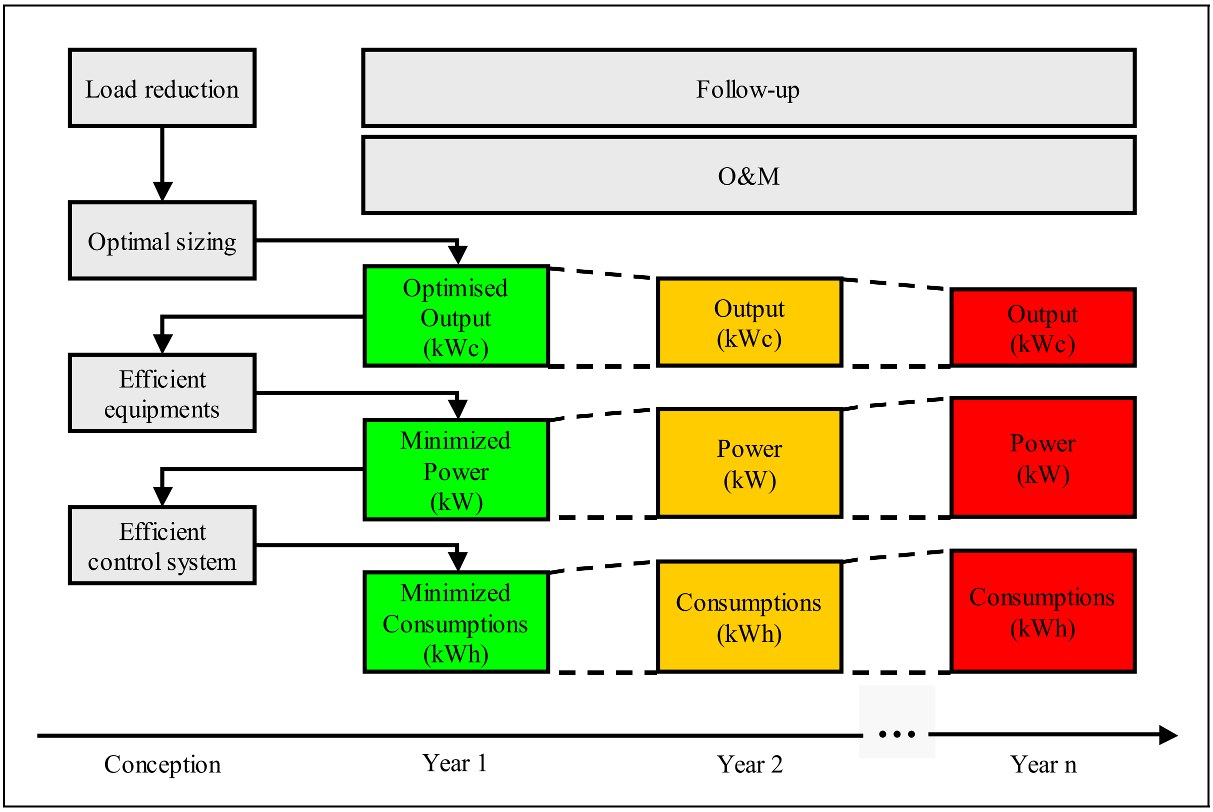

Figure 1: main examinations of the inspection

Power and time management
Correct sizing and rational choices ensure minimal cooling output to provide the required thermal comfort while minimizing the power absorbed. However, cooling needs are varying continuously because of occupancy (and other linked parameters) and solar gains. Despite the previous optimization, full load supply may remain too high at certain moments. Indeed, we noticed that the

sizing only on peak load is frequent. Flexibility strategies and power management devices allow to fit better or in real time the supply to the needs.

But, the “power” is only one part of energy consumptions. The operating time is the other term and its management is also an important way to achieve energy savings. Our experiments showed us that there was an important lack in that domain and some installations (cold generating systems, auxiliaries and ventilation) operate all night long and during weekends! That is why, any strategy or device allowing to better and quicker fit the system output close to the needs or to switch it on or off must be analyzed.

Operation, maintenance and follow-up
These only optimizations during the design phase cannot allow by themselves high efficiency during the whole lifespan. Indeed, O&M are crucial in order to avoid the inexorable decrease of performances, availability and reliability and the increase of operating costs. Therefore, the inspector must check O&M contracts and procedures but also their real application. O&M contracts are widespread for sites we inspected but the level of service is very variable according to building-owners.

The operation cannot be efficient without a good follow-up of energy parameters. A good metering is then essential so as to detect energy drifts or technical defaults much sooner before a breakdown occurs. However, during our inspections we noticed that relevant metering was almost exclusively implemented in largest buildings and installations. For low capacity systems, the only indicator is the annual operating time so that it is difficult for an inspector to judge performance changes. Therefore, any relevant metrology and indicator should be listed as good points by the inspector.

How to assess both sizing and efficiency?

If logbooks and annual reports including sufficient performance measurements are available, it is possible to limit the inspection only to the analysis of the documentation and few light qualitative observations. However, well-documented sites are often those that are correctly operated and maintained, in other words, buildings that would not need inspection. For other buildings, it is essential to inspect systems in operation to be able to assess quantitatively both sizing and efficiency as required by the EPBD article 9. Quantitative indicators are moreover essential in order to avoid or at least limit the subjectivity of inspectors.

Which measurements for the sizing assessment?
The CEN standard does not provide any typical method or measurement to do such assessment. The only considered way is to analyze commissioning results. However, during our on-site testing, we observed that the documentation often missed or was not sufficient. Moreover, the estimate of cooling needs is feasible room per room for lower capacity systems by using typical ratios (occupancy, lighting, air renewal rate etc…) but becomes too long and not accurate for larger systems. On the opposite, it is relevant to spend more time on an exhaustive calculation (manual, computer assisted or simulation methods) of cooling needs during an energy audit in order to increase the accuracy. If the two previous solutions are unfeasible, we observed that the only measurement of few indicators could confirm oversizing (table 2).

There are several oversizing indicators for cold generating systems. The first one is the average cycling duration for on/off-controlled air-conditioners. A too discontinuous operation of the compressor during a peak load period is synonym of oversizing. The annual operating time is also a good indicator if it is too low. On the opposite, a too high value can be due to undersizing or control defaults. However, the time counter does not take into account the different output levels that exist for most air-conditioners. The calculation of the full-load equivalent operating time for a certain time period from the division of energy consumption on the considered period by the certified full-load electrical power is thus better. The analysis remains the same. Finally, if the direct cooling load on-site measurement is impossible (split-systems, variable refrigerant flow systems), difficult (lack of metrology on the chilled water loop) or not accurate (measurements in air ducts), the electrical power can became a good indicator. The hourly recording and the yearly/seasonally averaging of that parameter can then be compared to the full load power. Too much cycling or too frequent operation at reduced output will reduce the average electrical load.

For the auxiliaries, the fan/pump efficiency calculation requires the air/water flow that can be difficult or costly to accurately measure, especially for air. If any flow-meter is installed, the flow can be extrapolated from fan/pump characteristics, speed and head measurements that remain easier but not necessarily more accurate. The extrapolated efficiency can thus be compared to the maximum value that could be reached in ideal operation condition (best efficiency point). For fixed speed drives, the magnitude of the difference between the two values is directly correlated to the oversizing. The efficiency loss for variable speed drives is less important because energy gains due to the fit of the regime remain largely predominant. A variable speed drive can however be oversized. If the speed (or flow) is much lower than the maximal value most of the time or during a peak load, the drive can be oversized or at least subject to control problems. Finally, a chiller-specific checking is the measurement of the chilled water return temperature from distribution networks. Indeed, if it is much lower than the theoretical value (9°C whereas typical 12°C) most of the time or during a peak-load period, it means that the water flow is too high in comparison to the cooling needs.

Table 2: some typical measurements to check the sizing of both cold generating systems and auxiliaries

	Measurement	**Oversizing when…**	**Method - Comments**
Cold Generating System	Mean cycling time (min)	Too low	1-hour recording
			During peak load On/Off controlled AC systems
	Electrical load (%)	Too low	Single point, 1-day recording, hourly (yearly average)
			During peak load if single point
	Load (W)	Too low	Single point, 1-day recording, hourly (yearly average)
			During peak load if single point Chillers & AHU only
	Cooling capacity per square-meter (W/m^2)	Much higher than reference values	Single point
			Benchmarking possible Need treated area
	Operating time (h/yr)	Too low	Seasonally, yearly
			Benchmarking possible
	Equivalent full-load operating time (h/yr)	Too low	Seasonally, yearly
			Benchmarking possible
Auxiliaries	Efficiency (%)	Much lower than maximum value	Single point
			Constant flow only Deduced from characteristics or calculated by head, flow, power
	Return water temperature (°C)	Much lower than maximum value	Single point, 1-day recording
			During peak load Chillers only
	Speed (rpm) or Flow (m^3/h)	Much lower than maximum value	Single point, 1-day recording, hourly (yearly average)
			During peak load (if single point) Variable flow only

Which measurements for the performance assessment?

The CEN standard provides only few solutions about efficiency assessment especially because it is much more difficult to estimate performances by single measurements. For example, the load varies continuously during a year - even a day - and has a great influence on the energy efficiency ratio. One single EER measurement would be largely different from a seasonally averaged EER (Seasonal Energy Efficiency Ratio, SEER) for example. It is then better to judge a system during a longer period that is more representative of the operation. That is why most of performance indicators are calculated from data aggregated on entire seasons or years.

Several measurements are possible on fans and pumps (table 3). The first one consists in an evaluation of the pressure loss in the whole network supplied by the fan/pump. Measuring the fan/pump differential pressure or electrical power (directly correlated to head by fan/pump laws) is then a good indicator. A regular follow-up of these values for the same regime even allows to detect drifts and then to anticipate actions. Fouling, especially on coils and filters, is among the network pressure drops. As for fans and pumps, a drift can be detected by a regular measurement of the differential pressure for similar flow conditions. Moreover, the coil fouling not only increases pressure losses but also decreases heat transfers and then the system efficiency.

Table 3: some typical performance indicators for auxiliaries

	Measurement	Indicator of…	Method - Comments
Losses	Fan & Pump Head (Pa)	Network pressure drop	Single point
			Constant flow only Regular follow-up
	Fan & Pump Power (W)	Network pressure drop	Single point
			Constant flow only Regular follow-up
	Filter & Coil pressure drop (Pa)	Fouling level	Single point
			Constant flow only Regular follow-up
Performance	Efficiency (%)	Pumping or ventilating performance	Single point, hourly (yearly average)
			Regular follow-up (if single point) Extrapolated (characteristics) or calculated (head, flow, power)
	Ventilating efficiency ratio (Wh/m^3) Pumping efficiency ratio ($Wh/m^3/Pa$)	Pumping or ventilating performance	Single point, hourly (yearly average)
			Benchmarking possible Extrapolated (characteristics) or calculated (head, flow, power)

These "loss" indicators do not mean anything without reference value measured when the installation was in a correct state of operation and maintenance. That is why these parameters must frequently be read as soon as the start-up of the installation. However, performance indicators exist and can be compared to current best practices or manufacturer maximum certified values. Once the flow is measured or extrapolated, it is possible to evaluate and compare the fan/pump efficiency to the maximum value that could be reached in ideal operation condition (best efficiency point). It is also possible to calculated pumping and ventilating efficiency ratios that can be compared between different installations. For example, the Swedish Indoor Climate Institute stipulates that if the ventilating efficiency ratio is lower than 0.4 Wh/m^3 the efficiency is good and if higher than 0.7 Wh/m^3 the efficiency is low.

All the previous measurements required portable metrology and take time. When available, it is essential to take advantage of the already installed metrology, especially energy meters that give access to typical ratios aggregated on a much longer period and for the whole system. Several typical ratios (table 4) require only regular readings of energy consumptions and any other parameter representing the building activity (KRARTI 2000) in order to get independency from the yearly activity level: number of rooms for hotels (Wh/room/year), beds for hospitals (Wh/bed/year), students for schools (Wh/student/year) or tickets for museums, concert-hall or any payable activity (Wh/ticket/year) etc… At least it is possible to use general area specific ratios as the annual energy consumption per square-meters (Wh/m^2/year). The comparison with statistics of buildings with similar characteristics could be a very quick way to check if evident efficiency improvements exist.

Table 4: some typical performance indicators for the whole air-conditioning system (auxiliaries included or not)

	Measurement	Indicator of…	Method - Comments
System	(Seasonal) Energy Efficiency Ratio	System performance of any building	Yearly/Seasonally follow-up (if energy meters) Hourly for summing on season or year Auxiliaries can be included or not
	Unitary energy consumption (Wh/m^2/yr)	System performance of any building	
	Yearly energy consumption per room (Wh/m^2/year)	System performance of hotels	
	Yearly energy consumption per bed (Wh/bed/yr)	System performance of hospitals	
	Yearly energy consumption per client (Wh/client/yr)	System performance of museums, concert-halls etc…	
	Yearly energy consumption per student (Wh/student/yr)	System performance of schools	

The necessity of qualitative observations

The inspection of air-conditioning systems is a very good initiative because it has professionals met with building owners during the operation of their installation. In reality, the contact is often lost just after the beginning of operation leaving the system without any follow-up. We observed that for a lot of systems, some obvious improvements with short payback times (especially on the management of operation times) can be easily found without long analyses.

The CEN standard understood well the necessity of qualitative observations to quicken the procedure, as it is unfortunately not possible to quantify every parameter during a one-day visit. For that part of the work, the inspector will have to use the documentation and to visit technical installations. To improve cost-efficiency of the procedure, it is important to valorize the work that had been already done especially in case of O&M subcontracts. For example, inspectors should use annual operation reports and logbooks if they are available and liable before doing any measurement. It is costly and time-consuming to measure what is regularly measured! Double-measurements can however be useful to check the correct calibration of the existing metrology and its liability.

Moreover, simple measurements at one moment do not give any information about the efficiency future trends, especially the improvement margin if actions were taken by the building-owner. For example, the efficiency of a “young” system that would have been optimally designed is likely to decrease with time because of its operation. The only advice of an earlier inspection would then to apply optimal operation and maintenance. On the opposite, poor performances may be the consequence of a malfunction, neglect or misuse So that the major advice is then to repair or change the considered equipment. Key O&M advice can be provided only after both qualitative visit of technical installations and analysis of the O&M documentation.

Cooling requirements
Seeking evident energy weaknesses in the building shell and internal loads is much more simple, quicker and less expensive than measurements, calculations or simulations. These methods should

remain the monopoly of energy audits. Our document lists several quick qualitative observations in order to detect possible efficiency weaknesses in wall insulation, thermal inertia, air infiltration, glazing, lighting and its management, electrical devices and their management etc… These items must be accompanied by the relevant documentation (commissioning results, plans, type of materials etc…). It is also essential to discuss with few occupants about the every-day use and thermal comfort to know about problems that might occur but unfortunately not during the inspection.

Efficiency
Systematic efficiency measurements are usually unnecessary. Once an inspector proved the sizing is optimized, to compare certified performances with best performances available on the market can be sufficient to assess the installation efficiency and find improvements. Several indicators like certified EER or IPLV (integrated part-load value) for cold generating systems, class (EC 1992) for room air conditioners, maximal efficiency or class for motors, AHU class (CEN 1998) can be used as they can normally be found in technical documentations or on equipment plates. If these indicators are not known because of a difficult access or an unavailable documentation, the EUROVENT database (EUROVENT) can be used for air-conditioners, air handling-units or fan coil units.

Power and time management
We observed in most buildings that there was a huge saving potential by the improvement of control and management of both supply power and time of operation. Some devices or practices specific to this kind of actions are essential to reduce energy consumptions. Check their existence and implementation can help in the assessment of the system performance. Our checklist summarizes what is essential in order to reach the highest efficiency level: the relevant zoning of the building, power reduction or variable speed on cold generating systems, modular structure (several smaller capacity generator in parallel ensure higher individual loads), thermostats, limited range for temperature set points (especially when controlled by occupants), timers or programmers or occupancy sensors, building energy management system (BEMS), flow control methods (some are more energy-efficient), free-cooling and/or free-chilling, heat-recovery on ventilation, cold storage etc… That analysis requires the highest expertise from the inspector so that documentation is essential such as characteristics (occupancy schedule, temperature set points, activity etc…) of each zone, technical manuals, description of control and management procedures.

Operation, Maintenance and Follow-up
Almost every checking about O&M provided by CEN is feasible on-site because simple and quick. Our checklists are also largely focused on O&M and on follow-up in general. In order to create a hierarchy in our checklists, we used air-conditioning breakdown statistics on HVAC (HALE 2001) in general, on rooftops (BREUKER 1998) and on chillers (COMSTOCK 2002). Indeed, weaknesses are primarily at heat exchangers, compressors, fans and pumps and control devices. We observed that most of inspected installations were subject to O&M contracts. Indeed, thermodynamic cycles are really affected by bad adjustments and required a regular follow-up by a professional to limit the frequency of breakdowns or minimize their effects. For building owners who already signed O&M contracts, inspection is synonym of extra costs. It seems logical that if O&M contracts and the follow-up are efficient, the frequency of inspection should be reduced.

In practice, the content and the efficiency of O&M contracts are variable so that it is fundamental for an inspector to check what O&M procedures are and if they are really and correctly applied on-site. Again, that analysis requires a lot of documentation such as O&M contracts and procedures, O&M logbooks, refrigerant charge receipt, etc… The optimal operation of both the thermodynamic cycle and auxiliaries can be analyzed especially if there are doubts about the operator seriousness. In that case, several measurements (figure 2) can be done and compared to optimal values. These reference values are known but as they depend on the refrigerant, it is difficult to give them precisely.

Finally, building owners need indicators to decide to invest or not. For the follow-up assessment, the inspector will list every “good points” such as the dedicated metrology and metering, the inclusion of a guarantee of results in O&M contracts, the energy indicators measured and benchmarked, the existence of annual reports from O&M subcontractors etc… Pieces of advice can be provided about the relevant metrology and indicators to use.

The duration of such a procedure is very variable from one site to another and we observed it depends firstly on the installation background (documentation, complexity, metrology, follow-up). But whatever the content of the inspection, that duration could decrease thank to the necessary presence of a responsible person (building owner representative, operator etc…) that can facilitate access to equipments and ensure the procedure exhaustiveness by taking upon himself the responsibility of any problem that might occur during the inspection.

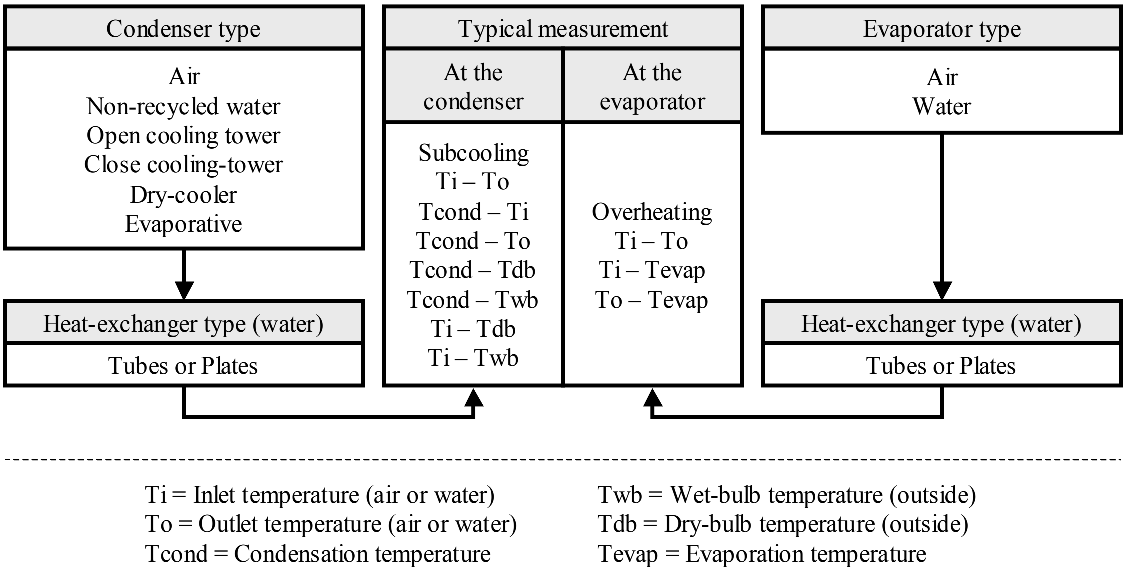

Figure 2: typical measurements on the thermodynamic cycle depending on the type of condensing and evaporating techniques (JACQUARD 2004)

What is the missing part?

The need for benchmarking

The regular follow-up of previously introduced ratios is always profitable for building owners because it allows to detect performance drifts from one year to another. Independent from annual results (tickets sold, beds or rooms occupied etc…) and occupation, they can also become independent from local climate using a cooling degree-days (CDD) correction. These ratios can moreover be compared between several buildings, which is much more interesting in the framework of inspection.

Nevertheless, we observed that because of a general lack of relevant meters, benchmarking was rarely used or remained the privilege of big buildings. Indeed, electricity sub-meters remain unusual in most buildings and aggregated electricity consumptions at the main electricity meter are much more difficult to use because of the mix of electricity uses. The inclusion of sub-meters in an existing system is technically difficult when it had not been thought at the launch. The second reason, which is also a consequence, is the lack of statistics. In fact, statistics exist but they are not reliable enough to accurately reflect the characteristics (climate, occupancy, shell, system etc…) of various buildings. Therefore, only large ranges of reference values are available.

To develop and update a database listing the measured ratios as soon as the beginning of regular inspection in Europe would be profitable for benchmarking. Indeed, by having access to a large part of the air-conditioned building stock in various sectors and for different climate, European inspectors could ensure by their measurements the good statistical representativeness of these ratios. For example, the cooling capacity per square-meter is easy to calculate and can be compared to maximum, minimum and average values for the same type of building, system and climate. It is then possible to assess sizing with regard to common practices in force in the country. The figure 3 is an example of statistical study about the cooling capacity per square-meter. More detailed statistics and information about each sites are confidential and under EDF ownership. These statistics are not enough significant because on the one hand they represent only installations advised and followed by EDF and on the other hand, certain categories do not include enough installations to lead to a representative ratio. It is however a good basis that should be extended to a larger stock.

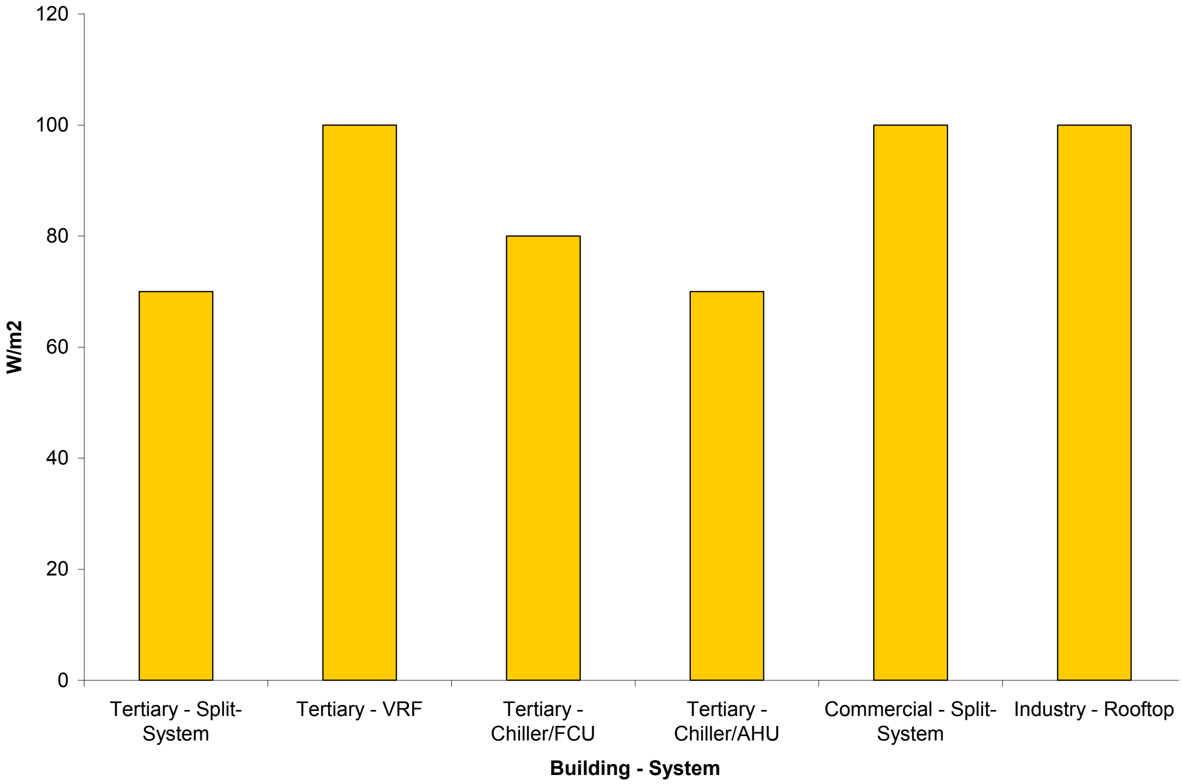

Figure 3: average installed cooling capacity per square-meters for several building and air-conditioning types in France (source: EDF*)

Minimum requirements

The main difficulty we had to face was the problem of subjectivity. Indeed, unlike the “roadworthiness tests for motor vehicles” for which each measurement is associated to a strict limit value, the inspection of air-conditioning systems contains a lot of qualitative observations such as the existence of some devices, equipments or procedures. In that case, how can be defined the mandatory improvements, replacements or simple changes that must be implemented by the building owner after the inspection? It is then essential to stipulate by a law or a standard which documentation, control devices, O&M procedures or metrology are mandatory or at least necessary. To define minimum requirements is the only condition to reach objectivity and homogeneity in inspector judgments and advise.

The same comment could be done to quantitative measurements. Indeed, the development of both metering and benchmarking should lead to the definition of reference (indicative), legal or standard (mandatory) values for energy indicators of air conditioning installations. Minimal requirements

* This diagram is only a small part of a larger study resulting of the follow-up of air-conditioning energy consumptions (100-building sample) in France carried out by EDF.

reinforce the incentive on building owners to have their air-conditioning system audited before investing for its improvement or replacement.

Conclusion

Easily applicable on-site, the inspection is a good initiative because it introduces a regular follow-up of any air-conditioning installations that is not necessarily done by building owners. A previous paper (DUPONT 2005) dealt with the feasibility of the CEN inspection at the member-state level whereas that one underlines some of the blanks of the standard at the site level. Indeed, the assessment of both sizing and efficiency demanded by the EPBD is difficult to do with the standard in that state. By a lack of minimal requirements from the CEN standard, the biggest part of the work remains for member-states so that the homogeneity of the measure is likely to be dissolved by national choices. Therefore, we proposed some additional quantitative measurements that could be included in the standard or in national procedures that should follow. The aim of these additions is to give more objectivity in the assessment and to be able to stipulate correctly which installations are energy-efficient and which have poor performances. As the inspection duration is limited, a method based only on measurements is impossible because too long. The paper thus underlined the necessity to complete measurements by a brief description and qualitative observations about installed equipments and their functioning.

However, a lot of work remains after that. By having access to building-owners technical installations, it seems relevant to create a database and develop statistics on major ratios the paper proposes. The essential future step would be to define good practice as limit values for energy ratios and minimal requirements about the documentation and metrology in order to accelerate the set-up of the measure and to facilitate its application. The incentive would then be greater because building owners would know which level they would have to reach for the next deadline. Hence, they could take advantage of the inspector conclusions to take further actions and invest directly in some improvements or even replacements.

That paper is only a small part of a larger project, aiming to define best practices for the inspection and auditing of air-conditioning systems. More complete and detailed results will be provided in a future paper. For that project, we acknowledge funding and moral support by ADEME (the French energy agency) and active cooperation by ‘Electricité de France’ (EDF) and ‘Ingenierie Tous Fluides’ (ITF).

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Energy Pumping Concepts to Address Simultaneously Occurring Cooling and Heating Demands in Air Conditioned Buildings. Status Quo, Comparative Analyses and Design Potentials

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Abstract
Energy pumping stands for the energy and cost saving methods applied to air condition buildings by removing surplus heat from rooms with cooling demands and adding it to those with heating demands. The energy pumping market is dominated by the Japanese VRF technology, which shows refrigerant piping within the building as the distinguishing feature, whereas the European Hydronic technology with water piping gains little success only. This paper covers comparative analyses of the VRF and Hydronic concepts, several applications of the Hydronic technology are introduced. The likely reasons for the yet little success of the Hydronic technology are discussed.

1. What does energy pumping mean?
Most of the studies on thermal comfort agree that even small changes in the room air conditions might have decisive impacts on the perceived climate. Therefore, at a high comfort level, office and hotel buildings are equipped with single room temperature control to allow the occupant a free choice of operation modes, in particular, the cooling and heating modes. As a result, some rooms of a building are cooled whereas other rooms of the same building are heated („simultaneous” cooling and heating). The simultaneous occurrence of cooling and heating demands is a significant feature mainly of modern light structures with large sized glazed surfaces and high requirements regarding comfort, with good insulation values and low energy storage capability of the building's thermal mass, with rare or even no window ventilation.
Energy pumping means that surplus heat is taken from rooms with cooling demand and added to rooms with heating demand. The question now is to what extent and how often is there a simultaneous demand for cooling and heating. To answer this question, the author performed a load simulation for an office building.

The calculations show that simultaneous demand for cooling and heating
- prevails when the outside air temperature ranges between 9 and 19°C,
- adds up to about 1,260 hours per year corresponding to 30 % of an operation time of 4,384 h/a in case of a 12 h/day operation mode,
- makes up for up to 30 % of the designed (peak load) demand and approx. 30 % of the annual demand for cooling and heating.

The calculated operation time of 1,260 h per year is rather high; hence it may well compensate the disadvantage that such simultaneous demand exclusively affects the low load range.

The units for energy pumping are especially suited for application in moderate outdoor climate (DIN 50019). Within this climatic zone, distinction can be made between two regions concerning the need for additional heating. With the refrigerant circuit being sized to the cooling load, it is only in Southern Europe that the heating performance will suffice for heating in winter. In Central Europe, a system sized in such a way will have to be equipped with additional heater(s). As an alternative, the refrigerant circuit could be sized to meet the heating demand, however, this would result in increased investment costs.

2. Energy pumping product series

Classification
The energy pumping units available on the market can either be allocated to Japanese or European air conditioning technology.
VRF (Variable Refrigerant Flow) stands for the Japanese technology with refrigerant pipes between the indoor and outdoor units as its distinguishing feature. The denomination VRV® (Variable Refrigerant Volume) is Daikin's trademark and practically a synonym for VRF. Most VRF equipment producers advertise the so-called inverter technology. Although the term „Inverter“ only gives a hint to the reversibility of the cooling cycle (invert = reverse), it now also implies the meaning of „capacity controlled or frequency converter controlled“. Inverter units prevail on the VRF market (more than 80 % [1]), so that „Inverter“ is more and more used in the sense of VRF.

The Hydronic, European technology, in contrast, uses water pipes inside the building and applies stepwise capacity control.

For both technologies, distinction concerning the designed operation modes is made between units for „Cooling only“, „Cooling OR Heating“ and „Cooling AND Heating“, in the following abbreviated “C only“, “C or H“ and “C & H“. „C only“ stands for a cooling unit; „C or H“ stands for a reverse cycle heat pump; „C & H“ is a system consisting of at least one outdoor unit and several indoor units. Each indoor unit is able to heat or cool independently from the others. The common pipework provides for the balance between heat supply and removal, meaning superfluous heat or cooling energy is „pumped to be redirected“ within the building. Hence, energy pumping represents the „Cooling AND Heating“ unit version.

Thermodynamic comparison
The air temperature in rooms with cooling demand and in rooms with heating demand is almost the same (20 to 24°C); hence „direct“ energy pumping is not feasible from the technical point of view. Therefore the energy pumping process takes place in several steps: the superfluous heat from a room of 24°C is absorbed by an energy carrier of 15°C, heated up in the outdoor unit to approx. 40°C and served to the room of 20°C.

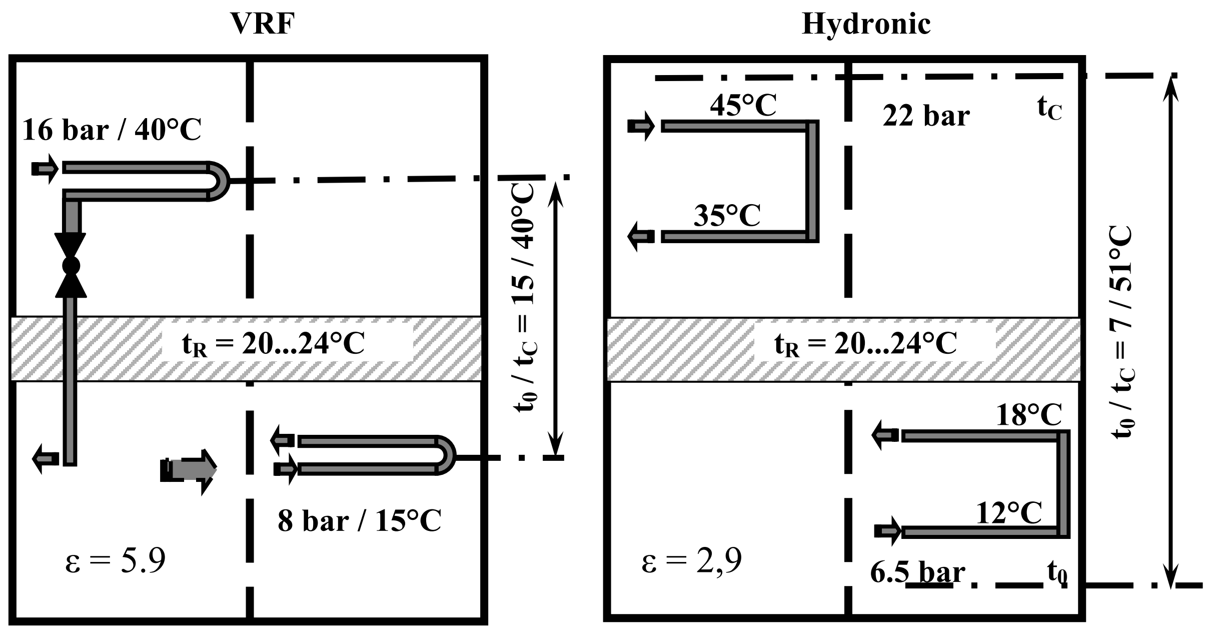

Figure 1: Thermodynamic illustration of VRF and Hydronic „C & H“ systems
refrigerant R407C, t_R – room temperature, t_0 – evaporation temperature, t_C - condensing temperature

Compared with Hydronic systems, the VRF technology is convincing in terms of the thermodynamic properties. The VRF system with DX evaporator and condensing unit uses only two heat exchangers (one in the indoor unit and one in the outdoor unit) whereas the Hydronic system with water as an intermediary energy carrier uses four heat exchangers (two in the indoor unit and two in the outdoor unit). Due to these two additional heat exchangers, the difference between the condensing and the evaporation temperature is almost twice as high as in case of the VRF system (figure 1). That means, the Hydronic system COP is only 50 % of the VRF system COP.

Technical features
A significant feature of the VRF „C & H“ systems is the 3-pipe layout between outdoor and indoor units. VRF systems implement the principle of direct evaporation / direct condensing. The built-in expansion valve allows the refrigerant from an indoor unit operating in heating mode to be served directly to the supply line of the indoor unit operating in cooling mode. Conventional Hydronic „C & H“ systems need 4 pipes in total for heating and cooling (chilled water supply and return pipes as well as heating water supply and return pipes).

The below listed technical data are confirmed by an analysis of the latest BSRIA studies for the German market [1, 2] and product catalogues of various manufacturers.

Technical data - VRF systems:

- Most of the currently offered products are estimated to be available on the market for max. 10 years.
- The unit cooling capacity ranges between 14 and 29 kW only; three unit sizes 5 HP, 8 HP and 10 HP (normal code for compressor absorbed input power in HP) are available. Larger sized systems are a combination of the above mentioned units.
- Mostly, three versions - „C only“, „C or H“ and „C & H“ - are offered.
- Manufacturers solve the question of piping between indoor units in quite different ways; assumedly it implies a certain degree of technical difficulties.
- Stepless capacity control is achievable down to the low load range (e.g. 24...100 % for Daikin products, 4...100 % for Toshiba products).
- Daikin and Fujitsu allow the connection of up to 16 indoor units, Toshiba allows 3 to 4 units only.
- Diversity (ratio of the total heating and/or cooling capacity of the indoor units to the cooling capacity of the outdoor unit) is a high-ranking issue. It may be up to 150 % (Mitsubishi).

It is assumed that the VRF system layout is sufficiently known [e.g. 3] so that no further explanations are given in this paper. In terms of energy, VRF systems are much better than Hydronic systems (refer to thermodynamic comparison above).

During their introduction on the market, a weak point of VRF systems was their limited pipework length and the vertical differential between indoor and outdoor units. Meanwhile, a pipework length of up to 100 m and a vertical differential of up to 50 m can be realized.

However, with VRF systems the overall quantity of refrigerant used and hence the max. attainable cooling capacity is limited because refrigerant pipework needs to be routed inside the building. The refrigerant charge is determined by the size of the smallest room where an indoor unit is installed. In case of a leak, the complete refrigerant charge will escape into the room so that dangerous concentrations may occur. According to a press report, a hotel had to be evacuated at night-time because of refrigerant leaks. The used refrigerant, R407C, is invisible and odourless. It is heavier than air and forms „lakes“ near the floor. A concentration of more than 20 % involves the risk of suffocation.

Technical data - Hydronic systems:

- A chiller series covers 2, mostly 3 cooling capacity ranges (definition acc. to BSRIA: < 20 kW, 21...50 kW, 51...100 kW, 101...200 kW etc.) and includes at least 5 or 7, often even 10 or more capacity steps.
- Mostly, two outdoor unit versions are offered: „C only“ and „C or H“.
- Capacity control is achieved by switching on and off the compressor, in case of several compressors by step control.
- An almost indispensable accessory of outdoor units is the hydronic module consisting of pump, flow switch, safety valve, expansion vessel, etc.
- Utilization of condenser waste heat by 20 %, 50 % and 100 % is possible.
- The indoor units - Fan Coil Units (FCU's) - are offered in various designs as 2-pipe-FCU's for „C only“ and as 4-pipe-FCU's for „C or H“.

The benefits of Hydronic systems compared with VRF systems result from the use of water as intermediary energy carrier:

- no refrigerant-conveying pipes and hence no refrigerant leaks inside buildings,
- no constraints regarding pipe length and vertical differential between indoor and outdoor units,
- no restriction regarding the outdoor unit cooling capacity,
- no necessity for specialist unit installation on site,
- possibility to connect an additional boiler to cover peak loads.

As already stated before, energy efficiency is the only but decisive disadvantage of Hydronic systems, and results from the use of water as intermediary energy carrier. The stepwise capacity control, however, does not involve any disadvantage since the inert water volume in the pipework mostly reduces the temperature fluctuations at the consumers. If upon switching on / off of the chiller the return water temperature varies by 6 K, the supply air difference of a connected fan coil unit is approx. 1.7 K only.

This shows that both systems, VRF and Hydronic, have their pros and cons, so that supposedly they should have equal shares in the market. This, however, is not the case, especially regarding the heat pump and energy pumping equipment.

Market situation in Germany

The VRF market is very dynamic and strongly competitive. More than 80 % of the VRF outdoor units sold in Germany have a cooling capacity of 23 kW or more [1]. On the average, 7 indoor units belong to each sold outdoor unit. More than 50 % of the sold VRF outdoor units were „C or H“ units (figure 2). The share of „C & H“ was 18 % and has been increasing in the last few years. For comparison: in Great Britain - the forerunner in VRF systems in Europe - the share of „C & H“ was 30 % already in 1998.

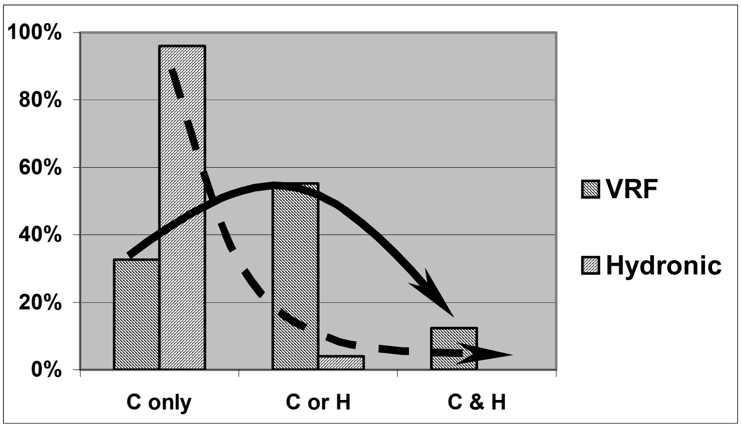

Figure 2: VRF versus Hydronic by unit version

Contrary to the VRF market, the market for „C or H“ and „C & H“ Hydronic system products is very weak (figure 2). On the one hand, this is due to the offensive marketing strategies of the Japanese manufacturers and the huge variety of VRF unit designs offered. On the other hand, it reveals the distinctive difference in the progress of the respective technology, especially with regard to the „C & H“ units. There are only a few Hydronic units for energy pumping on the market, their number is low and assumedly the production costs are high.

Almost all Hydronic outdoor units distributed in Germany are (non-reversible) chillers (96 % of the sold quantities) and there is almost no market for Hydronic heat pumps [2]. „C & H“ units are marginal although various European manufacturers have been reporting about the development of Hydronic „C & H“ units for years [4 – 7]. This is an apparent contradiction in view of the characteristic change of VRF products from „C only“ to „C or H“ and on to „C & H“ (figure 2).

In Germany, the market shares of VRF and Hydronic are almost equal (figure 3). The growth rates of the VRF market between 1996 and 2002 exceeded all expectations by far. They were 24.5 % on average (in the 1998 BSRIA study the forecast was 15 %). Hence, the somewhat cautiously projected growth of 5.3 % is not to be interpreted as a saturation of the market (table 1).

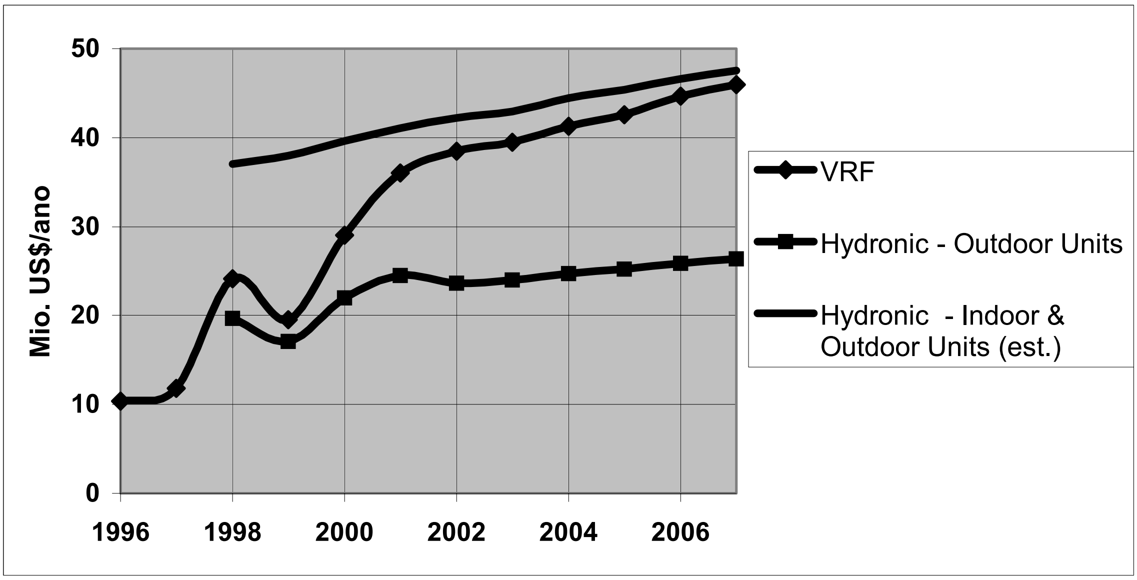

Figure 3: Market volume in Germany: VRF versus Hydronic (1 US$ = 0.95 €)

Table 1: Market growth rates

Growth rates	VRF	FCU's	Chillers
Average growth rate 1996 until 2002	24.5 %	4.6 %	1.7 %
Projected growth rate 2003 until 2007	5.3 %	2.4 %	2.7 %

3. Examples of Hydronic units for energy pumping

In conventional Hydronic systems, two energy carriers - chilled water and heating water - are generated for simultaneous cooling and heating throughout the year by chiller(s) and boiler(s). They are two independent systems, energy pumping is not the point. With the condenser waste heat being utilized, operation of the boiler(s) can be dispensed with, at least for some time. However, the costs for connecting an additional boiler may be quite high.

In the following, two Hydronic technology approaches for energy pumping are presented.

3HX heat pump of GEA Happel Klimatechnik GmbH

GEA Happel's heat pump for combined cooling and heating [4, 5] has three heat exchangers (resulting in the denomination 3HX): a water-based evaporator and condenser and an air-based heat exchanger acting as evaporator or condenser as required (figure 4). Although such air-based heat exchangers are a fixed component of each reversible chiller using air as the heating/cooling source, they are not freely available on the market so that each producer is forced to develop his own solution.

The heat pump for combined cooling and heating features 5 operation modes („cooling only", „heating only ", „cooling and heating balanced", „cooling decisive", „heating decisive") and one auxiliary operation mode „defrost". Switching-over between the various modes takes place in the refrigerant circuit presenting high requirements to the control algorithm and instrumentation.

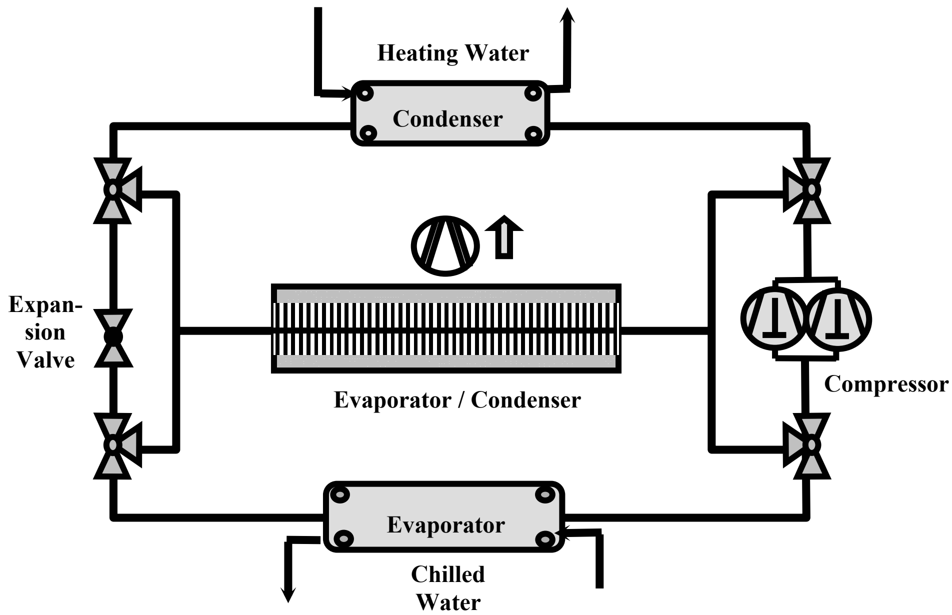

Figure 4: Heat pump for combined cooling and heating 3HX of GEA Happel

With this concept, connection of a boiler would be quite expensive. Such additional cost for a boiler connection could lead to the failure of the rather costly unit on the market.

Colt-Caloris® of Colt Int. GmbH
Another very promising approach is the use of a neutral-temperature water circuit with connected outdoor and indoor units. All units are designed as reverse cycle heat pumps (figure 5) [6].

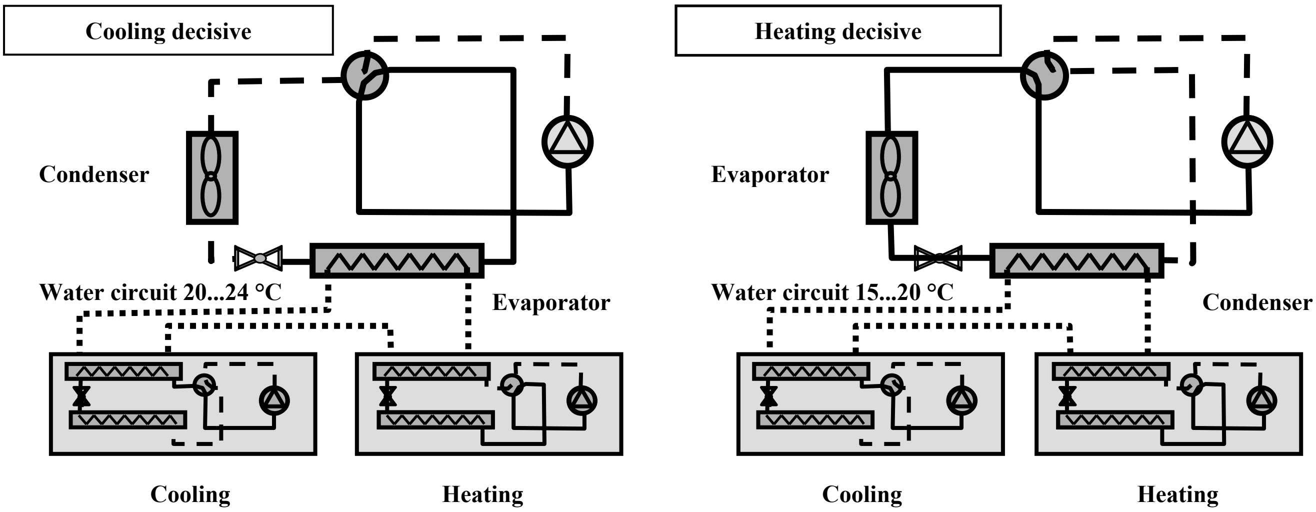

Figure 5: Colt-Caloris®

The simple boiler connection is another benefit of this concept. An offensive marketing strategy could lead to a significant success of such Hydronic units on the market, particularly in Germany. However, the product range of indoor units is quite limited with regard to capacity steps and models. With low quantities, the overall production costs will supposedly exceed the VRF mass production costs by far.

Other approaches
For reasons of completeness, there are at least two other Hydronic approaches which should be mentioned here. The concept of Dipl.-Ing. W. Gößling (Hiddenhausen, Germany) connects 5 heat exchangers with a cooling tower (figure 6); the energy plant GEOZENT® of Zent-Frenger [7] integrates a geothermal heat exchanger (figure 7). Both systems provide various operation modes, change-over from one mode to the other takes place in the water circuit. The benefits of such concepts become obvious particularly in systems of higher cooling capacities from 40 to 160 kW or more.

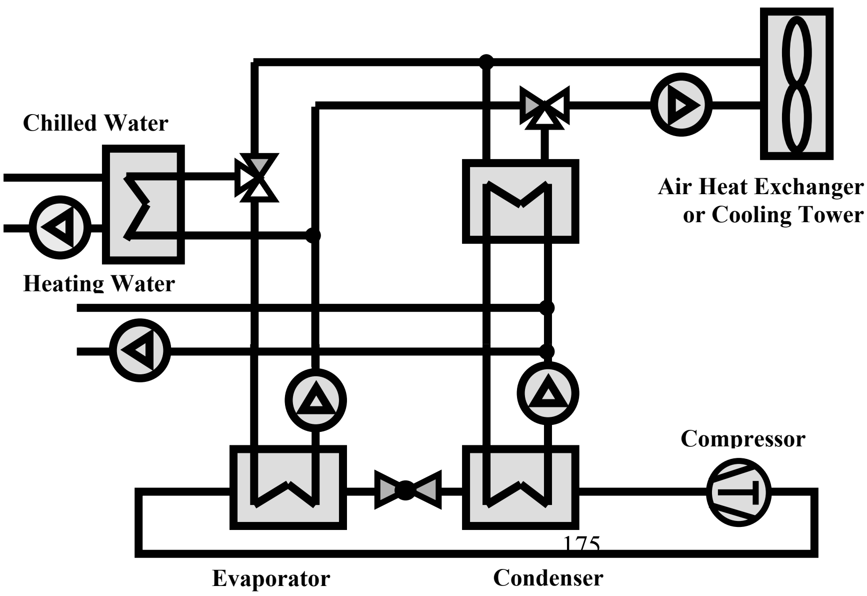

Figure 6: Hydronic concept of Dipl.-Ing. W. Gößling

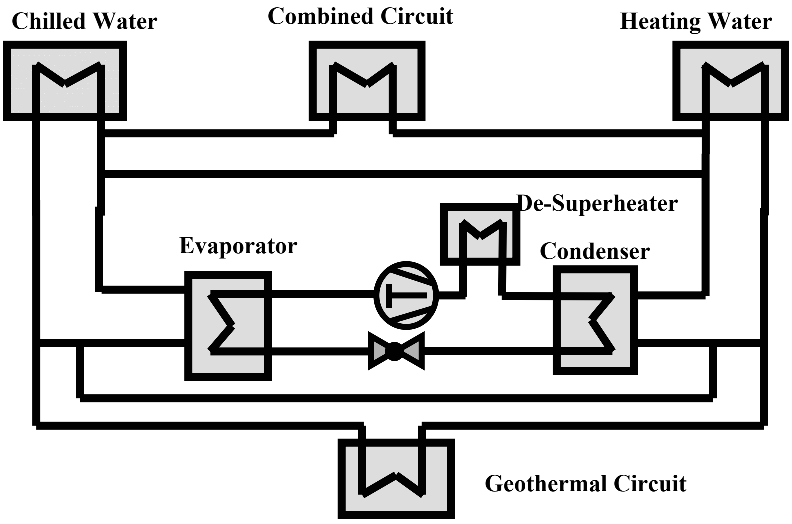

Figure 7: GEOZENT® of Zent-Frenger

Conclusion

The Japanese VRF units for energy pumping offer highly improved comfort at low extra cost. Such price strategy is possible by the mass production of VRF units. The European Hydronic units are new developments with currently low quantities. Hence their price is accordingly higher compared with the VRF competition. The present failure of Hydronic units on the market is not only due to the offensive marketing strategy of the Japanese manufacturers and the variety of design models offered but can also be explained with the different level of progress in the respective technology.

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Selection of procedures for air conditioning audit and definition of the associated training package

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Abstract

In the current transformation of the air conditioning (AC) market, important efforts should be achieved to improve the energy efficiency of these systems all along their life cycle. To detect and define the performance degradation of these facilities, a global approach has to be developed and the complexity of the systems implies the creation of reliable and efficient audit procedures and methods. In the AUDITAC project, we will describe the features of the two levels audit methods; pre-audit (or walk-through) and (detailed) audit.
In order to support the harmonisation of the implementation of the AC systems inspection, starting from the inspection schemes already on the market, we assessed their effectiveness and establish a link with the operation and maintenance practices. The decision for renovation will be developed in its aspects of energy savings and economic feasibility.
In order to disseminate and involve easily the AC actors in the audit methods, we have developed a basic training package (TP) about auditing AC facilities.
This tool has been created to prepare and introduce air conditioning actors (energy managers, facilities owners, technicians related to AC etc…) to the compulsory inspection and to disseminate the advantages and opportunities that the subsequent audit can give.
The audit approach is globally explained in the TP from cooling production to distribution, operation and maintenance and finally control strategies. Quantitative indicators for best practices and improvement examples are showed to support decision of renovation.
Basically, the TP has been designed for a public with an educational level of post-high school and can be used in different scenarios (students with HVAC class, inspection technicians, energy managers' information etc…).

The audit in the life of air conditioning facilities

An AC system is a complex system of which the optimal management requires a deep knowledge of the system coupled with other aspects such as the building structure and use. The European Community (EC) promotes the energy improvement of these systems through the compulsory inspection of these facilities in the frame of the Energy Performance of Buildings Directive (EPBD, 2002). Inspection itself is just a motivating mean for the AC actors to improve the energy efficiency of the systems and reduce energy consumption. To reach these objectives the subsequent, necessary step is the audit.
So, while the aim of the inspection is to follow periodically the correct management of the facility through a quick visit of the plant and a study of the available documentation, the aim of the audit is the research of any possible efficiency improvement that goes beyond superficial assessment and it requires further investigations to evaluate the possibilities of improvement and quantify the savings. Audit differ also from the simple maintenance of the facilities, the aim of which is limited to guarantee the basic operation of the plant, and takes care for the efficient operation of the system and the comfort of the occupant: waste of energy may be avoided and maintenance and operation activities oriented in order to reduce system consumptions, keeping the comfort level of the occupants satisfactory or even improving it.

In this paper we consider the audit in a larger perspective of the plant life. The life of a system can be very complex following the life of the building and different cases can exist. About the design of the system, we can consider three main possibilities: an *existing* building needs for a *new* plant, in an *existing* building a *new* plant is required *instead* of the *existing* plant, a *new* plant is designed for a *new* building.
In the first case, a new plant has been designed in order to improve the comfort level of the existing building adapting its structure to the construction which hasn't be designed to include it.
In the second case, the renovation can follow a decision of entire building renovation of only for the plant for reasons of discomfort, failure or obsolescence of the system or accidents (fire or flood).
In the third case, the system is born with the building and their designs have been conceived to match.
After this phase (design and construction) the normal life of the plant begins with operation and building occupancy. During its life many events can require the intervention of the audit which should constitute a constant aspect as O&M. Audit can intervene in decision of renovation (total or partial), it can be subsequent to the modification of the use of the building, it can be in parallel with repair and corrective maintenance in case of failure, it can derive from the wish of the owner of O&M improvement for energy savings or it can be developed on the basis of the advices released after an inspection. Therefore audit can be performed many times all along the life plant until the stop of its operation for definitive failure or renovation.

An example of the life of a system and of one of these events is represented in Figure 1.

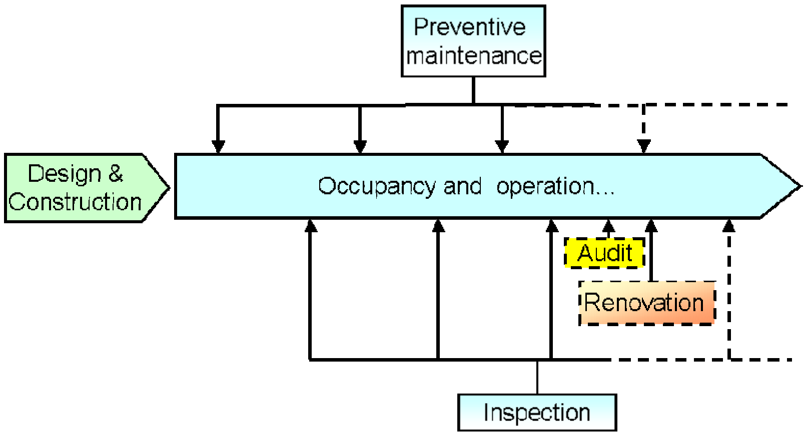

Figure 1. Lifetime of an AC plant with various steps

In the AUDITAC project (AUDITAC 2005), we distinguish between two levels of audit: a pre-audit with simplified procedures that is used to first individuate the point of energy waste and to find out the energy conservation opportunities (ECOs). Some improvement and low cost action can be undertaken directly after the pre audit when they are easy to implement and their impacts are easy to assess. An example of this type of easy to implement action is the change of the temperature setpoints.

In order to implement more complex procedures and quantify the savings from the ECOs, another procedure is needed: the audit or detailed audit. At this level, complex calculations, measurements and simulations can be performed in order to obtain quantitative indicators of the possible savings and to evaluate economical parameters that allow to the owner to compare different solutions, to advise his decision and face the investment required.
These steps are represented in the scheme of **Figure 2** with some example of action and opportunity.

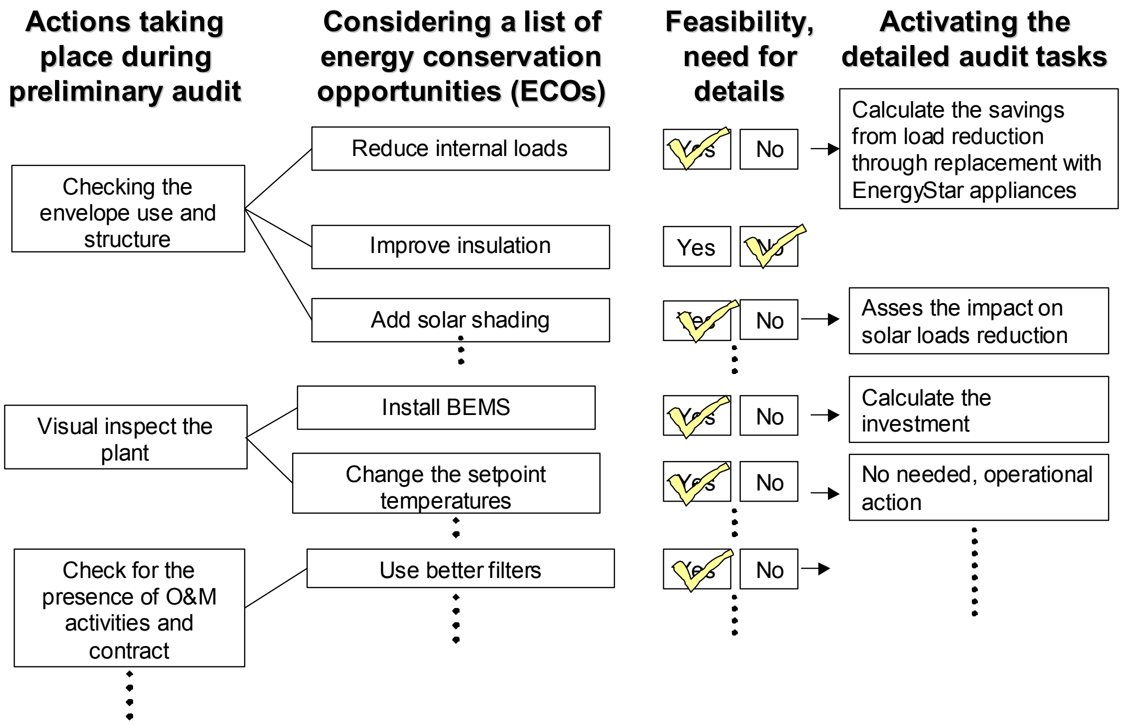

Figure 2. Main steps of the audit: from pre audit to detailed audit actions.

Aspects of the incoming inspection for air conditioning facilities

There is still much uncertainty about the effects expected from the implementation of the inspection of AC facilities (Article 9 of Energy Performance of Buildings Directive (EPBD 2002)). The Member States are exploring the weight to give to the various aspects: things seem so simple for the heating side! The basic difference between heating and air-conditioning is the following: in air conditioning it is enough to check frequently the state of the main equipment (the boiler for heating, in our case the compressor) and to think about the system at the end of its lifetime. For air conditioning, the system is the problem! We could even say that the compressor is the less sensitive part of the system.
Due to accumulated knowledge about heating efficiency, the Member States introduced a reasonable level of flexibility in the heating inspection section (Article 8 of the EPBD). As a result the difference between heating and cooling systems inspection is in the other direction that one could expect: while flexibility has been decided for heating due to accumulated knowledge, at the same time we have very ambitious and wide inspection for air conditioning, leaving the Member states the responsibility to introduce their own AC inspection scheme in spite of fact that the AC systems are very complex.

So the Member states are working for the national implementation of inspection in a challenging context. Nobody has solved yet the problems of creating and maintaining a file of installation to be inspected at low cost. The Member States still have to decide.
We can expect many things from an inspection, but it will not be the same inspection depending on the expectations:

- Objective of safety (see Italian inspection of boilers)
- Objective of reliability and cleanness: one seems to seek to check maintenance, not the performance.
- Objective of energy efficiency assessment

In the regulatory impact assessment we cannot compare the price of a checking maintenance and the benefit of an energy audit. It is this distorted comparison which is likely to be often made.
In many countries the standard prepared by the CEN will be taken into account for the methodology of inspection scheme (CEN 2005).

The compulsory inspection of AC systems of more than 12 kW makes sense if we consider the energy savings that can be achieved. The potential benefits can be important if we target them correctly in the definition of the inspection. The CEN standard is an important part of this effort, because it can indicate better than the short Directive article the objectives of inspection, show possible ways of achieving the goal, while leaving freedom for technical progress.
The real purpose of the article 9 is to initiate a continuous improvement process that will set up higher quality standards in air conditioning: either diagnosis and correction of existing systems operation (on short term) or audits followed by investments and improvement works (on a longer term). It should provide sound bases on which professionals will then work: operators, auditors, and contractors.
A question that still remain open is what will be the real skills necessary of the audit or inspector to full benefit from the inspection and audit? The cost effectiveness of the measure will be dependent on the experience required for the inspection and the subsequent energy savings. In our experience, the diagnosis of air-conditioning problems seems to be beyond the ability of many, even in the presence of training because of the complexity of the systems and the variety of competences required for a complete evaluation of the energy conservation opportunities. The need for expert auditors would increase the cost of the inspection itself and reduce the availability of professionals able to do it to face the important workload. It would be interesting to introduce expert systems and tools from the design of air conditioning systems until the installation to make the inspection and audit feasible from a master craftsman or similar. A double effort would be required: in the training development of inspectors and auditors and through interactions with manufacturers and installers devoted to define the main characteristics to introduce in the systems to reduce the inspection last and make more visible all the information required from the inspector.
Moreover, in the case of EPBD one could desire a consistency between energy performance certification and inspection: consistent advice, possibility of improving actually the grading by doing what the inspection recommends. In that case the inspection has to be tailored to the methods used to certify performance.

Forward a better management of the AC facilities: pre-audit techniques

In a pre-audit procedure one detects the errors in the AC systems with visual detection and with measurements. Pre-audit involves minimal interviews with site operating personnel, a review of facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building operation and identify glaring areas of energy waste or inefficiency. Typically, only major problem areas will be uncovered during this type of audit. This level of detail, while not sufficient for reaching a final decision on implementing proposed measures, is adequate to prioritize energy efficiency projects and determine the need for a more detailed audit. Pre-Audit activities, in general order, should include:

- Identify HVAC (all energy) system
- Evaluate the condition of the system
- Find out and describe the possible impact of improvements to those system
- Write up a pre-audit report

Pre-audit is the less costly audit, but a pre-audit can yield a preliminary estimate of savings potential and a list of low-cost savings opportunities through improvements in operational and maintenance practices. The pre-audit information should be used for a more detailed audit later if the preliminary savings potential appears to warrant further auditing activity.

The Pre-audit Process

The first step should be a collection of information. The information may be collected on the structural and mechanical components that affect building energy use and the operational characteristics of the facility. Much of this information can be collected prior to the site visit. Evaluating energy use and systems before going on-site helps identify potential savings and makes best use of time spent on-site.

The pre-audit consists of three distinct steps:

- preliminary data collection and evaluation,
- site visit,

- analysis and reporting.

Preliminary Data Collection
A pre-site review of building systems and their operation should generate a list of specific questions and issues to be discussed during the actual visit to the facility. This preparation will help ensure the most effective use of on-site time and minimize disruptions to building personnel. A thorough pre-site review will also reduce the time required to complete the on-site portion of the audit. The first task is to collect and review two years worth of utility energy data for electricity. The HVAC system consumption data should be provided if the system is measured separately. This information is used to analyze operational characteristics, calculate some energy benchmarks for comparison to averages, estimate savings potential, set an energy reduction target, and establish a baseline to monitor the effectiveness of implemented measures. The building manager should provide occupancy schedules, operation and maintenance practices, and plans that may have an impact on energy consumption. This kind of information can help identify times when building systems such as lighting, recirculating pumps or outside air ventilation can be turned off and temperatures set back. The building manager should provide also all plans documentation. If the data are not available and if they don't correspond to the reality then the first action should be to help to collect the data.

Analyzing Energy Data (Cooling Energy Benchmark)
The Cooling Energy Benchmark (CEB) could be calculated to compare energy consumption to similar building types or to track consumption from year to year in the same building. The CEB is calculated ratios based on the annual consumption and the area (gross square) of the building. CEB is a good indicator of the relative potential for energy savings. A comparatively low CEB indicates less potential for large energy savings. By tracking the CEB using a rolling 12-month block, building performance can be evaluated based on increasing or decreasing energy use trends. This method requires a minimum of two years of energy consumption data to establish the trend line and values including weather correction.
Caution has to be used in benchmarking in order to compare comparable values between different buildings. The best benchmark method would take into account different parameters (weather, sector, air control factors etc.). Actually, there are few air conditioning benchmark references and often general benchmarks are most commonly used and available.

Looking at Loads for cooling
Cooling loads include lighting, office equipment, appliances, solar gains and specific processes. High loads are in general easy to detect and the energy management efforts should be focused in these areas. High loads may reveal opportunities to reduce consumption by making improvements to the air conditioning equipment, temperature controls, the building envelope, or to other systems which are affected by operation. After utility use has been allocated, the pre-auditor should prepare a list of the major energy-using systems in the building and estimate the time when each system is in operation throughout the year. The list will help identify how each system uses energy and potential savings. Building systems can then be targeted for more detailed data collection. One of the easiest ways to evaluate energy data is to watch for the trends in use, demand, or costs over time. Either graphing two or more years of monthly data on one graph or graphing only the annual totals for several years can help.

Building Profile
Obtaining mechanical, architectural, and electrical drawings and specifications for the original building as well as for any additions or remodeling work that may have been done is the first step to creating a building profile. Any past energy audits or studies should be reviewed. The auditor can use this information to develop a building profile narrative that includes age, occupancy, description, and existing conditions of architectural, mechanical, and electrical systems. The profile should note the major energy-consuming equipment or systems and identify systems and components that are inherently inefficient. A site sketch of the building should also be made. The sketch should show the relative location and outline of each building; name and building number of each building; year of construction of each building and additions; dimensions of each building and additions; location and identification numbers of utility meters; central plants; and orientation of the complex.

While completing the pre-site review, the auditor should note areas of particular interest and write down any questions about the lighting systems and controls, HVAC zone controls, or setback operation. Other questions may regard equipment maintenance practices. At this point the auditor should discuss preliminary observations with the building manager or operator. The building manager or operator should be asked about their interest in particular conservation projects or planned changes to the building or its systems. The audit should be scheduled when key systems are in operation and when the building operator can take part.

The Site Visit
The site visit will be spent inspecting actual systems and answering specific questions released from the preliminary review. The amount of time required will vary depending on the completeness of the preliminary information collected, the complexity of the building and systems, and the need for testing equipment.
Having several copies of a simple floor plan of the building will be useful for notes during the site visit. A separate copy should be made for noting information on locations of HVAC equipment and controls, heating zones, light levels, and other energy-related systems. If architectural drawings are not available, emergency fire exit plans are usually posted on each floor; these plans are a good alternative for a basic floor plan.
Prior to touring the facility, the auditor and building manager should review the auditor's energy consumption profiles.

Analysis and Reporting
Post-site work is a necessary and important step to ensure the pre-audit will be useful. The auditor needs to evaluate the information gathered during the site visit, research possible energy conservation opportunities (ECOs), organize the audit into a comprehensive report, and make recommendations on improvements. Report from pre-audit with possible ECOs should be used as input for other audit types.

Deciding improvements and renovation: the opportunities from detailed audit

Following the pre-audit advises and results, the audit procedure allow to go deeper in the research for energy efficiency through the following actions (adapted from Portland 1997, Thurmann and Younger 2003, Hansen and Brown 2004).

Verification of system performance
Maintenance departments can use the energy conservation opportunities (ECOs) in order to enhance the energy efficiency of HVAC systems; verification of system performance testing is a total system approach, as in a HVAC each component might work fine by itself, but unless the entire system has been performance tested there is no assurance that the HVAC system is functioning in an energy efficient manner.
Before making a final go – ahead decision to upgrade, change or retrofit any HVAC system it is important to know exactly the system performance data and to predict the effectiveness of costly changes.

O&M for energy efficiency
Building Operation and Maintenance (O&M) is the ongoing process of sustaining the performance of building systems according to design intent, the owner’s or occupants’ changing needs, and optimum efficiency levels. The O&M process helps sustain a building’s overall profitability by addressing tenant comfort, equipment reliability, and efficient operation. Efficient operation, in the context of O&M, refers to activities such as scheduling equipment and optimizing energy and comfort-control strategies so that equipment operates only to the degree needed to fulfill its intended function. Maintenance activities involve physically inspecting and caring for equipment. These O&M tasks, when performed systematically, increase reliability, reduce equipment degradation, and sustain energy efficiency.

Selection of procedures air conditioning audit and use of the associated training package about auditing air conditioning facilities

Building operation and maintenance programs specifically designed to enhance operating efficiency of HVAC can save 5 to 20 percent of the energy bills without significant capital investment, utilizing strategies that facility managers, energy managers and property managers can use to integrate energy-efficient operation into their organizations O&M programs and to obtain support from senior management.

An O&M site audit is a systematic method for identifying ways to optimize the performance of an existing building. It involves gathering, analyzing, and presenting information based on the building owner or manager's requirements. The goal of the assessment is to gain an understanding of how building systems and equipment are currently operated and maintained, why these O&M strategies were chosen, and what the most significant problems are for building staff and occupants. Most projects require the development of a formal assessment instrument in order to obtain all the necessary O&M information. This instrument includes a detailed interview with the facility manager, building operators and maintenance service contractors who are responsible for the administration and implementation of the O&M program. Depending on the scope of the project it may also include an in-depth site survey of equipment condition and gathering of nameplate information. An O&M assessment can take from a few days to several weeks to complete depending on the objectives and scope of the project.
The audit identifies the best opportunities for optimizing the energy-using systems and improving O&M practices. It provides the starting point for evaluating the present O&M program and a basis for understanding which O&M improvements are most cost effective to implement.
The O&M assessment may be performed first of all as part of a detailed energy audit because it offers ways to optimize the existing building systems, reducing the need for potentially expensive retrofit solutions, besides because implementing the low-cost savings identified in the assessment can improve the payback schedule for capital improvements resulting from the energy audit.
The greatest benefit of performing a building O&M assessment is informational. The information resulting from an O&M assessment can be used to help prioritize both financial and policy issues regarding the management and budget for the facility. It presents a clear picture of where and what improvements may be most cost effective to implement first. The assessment process, depending on the owner's or manager's requirements, can also provide direct training and documentation benefits for O&M staff.
Depending on the goals for performing the assessment, typical benefits may include:

- Identifying operational improvements that capture energy and demand savings
- Identifying operational improvements that positively affect comfort and IAQ
- Improving building control
- Developing a baseline report on the condition of major HVAC equipment
- Identifying issues contributing to premature equipment failure
- Identifying ways to reduce staff time spent on emergencies
- Increasing O&M staff capabilities and expertise
- Determining whether staff require additional training
- Developing a complete set of sequences of operation for the major HVAC systems
- Evaluating the BEMS for opportunities to optimize control strategies
- Determining original design intent and the cost to bring the building back to original design
- Providing a cost/benefit analysis of implementing the recommended O&M improvements
- Developing an operating plan and policy to maintain optimal building performance over time.

The best benefits keep on giving long after the process is completed. For example, the final master log of recommended improvements along with the estimated savings allows an owner or building manager to prioritize and budget accurately for the implementation process. Also, minor problems that could be solved during the assessment may begin to reduce energy costs and improve comfort immediately; equipment life may be extended for equipment that may have failed prematurely due to hidden problems, short-cycling, or excessive run time.

How much auditing the O&M costs is influenced by several factors:

- The number and complexity of the buildings, systems, and equipment involved

- The number and type of assessment objectives
- The availability and completeness of building documentation
- The availability and expertise of the O&M staff.

A project with several objectives will naturally cost more than a project with fewer objectives. Also, a project with complicated controls and numerous pieces of equipment will cost more than a simple building with only a few pieces of equipment. The owner must have a clear vision for what the assessment needs to accomplish and impart that vision to the O&M consultant.

Retrofit

The central cooling plant is a critical component of any building of facility. As with all mechanical equipment there is a finite useful life for the equipment. While an extensive maintenance program can extend this useful life, there comes a time when replacement of the equipment is necessary. In addition, retrofit projects can be undertaken as part of an efficiency enhancement strategy or as a result of changes in the use or needs of the facility.

The first consideration in undertaking a central plant retrofit project is that the scope of the project should not be limited to simple replacement of the components. Because this project is usually taking place at least 20 years after the facility was originally constructed, the system would be re – engineered based on the actual loads and usage of the facility. This will help to promote the goals of increasing efficiency and reliability.

There are a number of reasons for this re – engineering. The first involves the original equipment selection. In general, engineers are conservative in their load calculations and equipment selection: this can lead to inefficient operation. A second reason for re – engineering is due to changes in the peak load or load profile for the facility which affect equipment selection.

Technology changes are another big reason for re – engineering the central plant. One major advance is in the area of control systems. Today’s control systems have much greater capacity that the systems that were available when the plant was first constructed, and the limitations in the control strategies sometimes played a significant role in the design of the central plant. An offshoot of this is the inclusion of digital control panels in the equipment. This greatly improves the operation of the equipment as well as providing availability of better information on the operation of the equipment. Strategies like variable flow in chillers were difficult to achieve with analog control panels. Another big change is the availability of variable speed drives and the efficiency improvements that can be gained from their proper application. Potential uses are for secondary pumping systems, chilled water and condenser water pumps for variable flow chillers, chillers and cooling tower fans.

As in many cases, there are multiple solutions to any problem and different ways to design a system that will produce the desired result, cooling for people or equipment. The basic process of a retrofit project is similar to a new construction project, but in most cases the facility will continue to operate during the retrofit project. Another important consideration is the opinion of probable costs. It is necessary to have a good idea of the first cost of each option to provide a good base for the analysis. The major factor in the evaluation will be the estimates of operating costs. Since there will be a significant investment in the retrofit project, it may be easier to justify efficiency improvements based on incremental costs and savings instead of having to justify the entire cost of a project solely by the anticipated efficiency gains. There are several levels of estimates of operating costs that can be utilized: the simplest methods can be used as a screening tool to reduce the amount of simulation work that may be required. The ultimate analysis tool is a full energy simulation, using one of the available programs.

Investment audit

The foremost limitation of the traditional energy audit is that it is based on a “snap shot” approach. Auditors assumed conditions observed during the audit would remain the same for the life of the equipment or the project. An audit today must support a multi – year energy efficiency project and provide quality investment guidance. As the energy efficiency industry matured, projects became more complex and risk analysis became more sophisticated, the need for information grew too. An important aspect of the investment grade audit is the Measurement and savings Verification (M&V) protocol. M&V requires an established and clearly defined historical base year as well as the necessary procedures to create an annually adjusted baseline.

At the same time, energy efficiency project financing was getting easier to find, but financiers were asking more sophisticated questions about risk. The risk assessment should be done for an energy efficient project, either an "in house" effort, or a comprehensive project to be accomplished by an ESCO; it can be expressed as a series of steps leading to the realistic calculations of the payback periods for the proposed measures.

Improvements through BEMS
Once a Building Energy Management System (BEMS) is in place and fully operational, the facility manager who will supervise its operation may look toward optimisation. Before trying to optimise a system, it is important to understand basic BEMS capabilities. Features may vary widely from model to model, but some basic capabilities are almost universal.
The standard BEMS capabilities are:

- Scheduling
- Set-points
- Alarms
- Safeties
- Basic monitoring and trending.

With each of these features, there are opportunities to move beyond minimal utilization without significant effort or complexity.
Selected control strategies that can save energy or reduce demand are in the following table.

Scheduling	**Lockouts**	**Miscellaneous**
• Holiday scheduling • Zonal scheduling • Override control and tenant billing • Night setup/setback • Optimum start • Optimum stop • Morning warm-up/cool-down	• Boiler system • Chiller system • Direct expansion compressor cooling • Resistance heat	• Simultaneous heating/cooling control • Zone-based HVAC control • Dual duct deck control • Chiller staging • Boiler control • Building space pressure • Variable speed drive control • Heat recovery
Ventilation Control	**Energy Monitoring**	**Lighting**
• Carbon dioxide • Occupancy sensors • Supply air volume/OSA damper compensation routines • Exhaust fans	• Whole building or end-use • kWh or demand	• Lighting sweep • Occupancy sensors • Daylight dimming • Zonal lighting control
Air-Side Economizers	**Resets**	**Demand Control**
• Typical air-side • Night ventilation purge	• Supply air/discharge air temperature • Hot deck and cold deck temperature • Mixed air temperature • Heating water temperature • Entering condenser water temperature • Chilled water supply temperature • VAV fan duct pressure and flow • Chilled water pressure	• Demand limiting or load shedding • Sequential startup of equipment • Duty cycling

A training package about auditing AC

In the frame of the AUDITAC project, we have developed a basic training package (TP) that resumes the results showed in the previous paragraphs and include some other analysis and important conclusions of the project.
Hence the main objectives of the training package are:

- To create a common core of knowledge and information from the different competences, necessary to describe an exhaustive audit of AC facilities
- To show the (economic and energy) best practices and best solutions
- To rise awareness in the audience about the stakes of the AC energy use at international and individual level
- To motivate the AC actors to go through audit in order to improve the energy efficiency of AC facilities
- To prepare the public to the compulsory AC inspection and combine it with audit.

Who may benefit from this training package
The impulse to audit expected from the new configuration of the energy market makes necessary the dissemination of the knowledge about the AC systems efficiency improvements to the actors. More than maintainers and AC experts, a large new public is now involved in the improvement of the AC systems as facilities owners, energy managers, energy advisors, technical staff of public buildings, technicians with skills related to AC etc.
The TP is supposed to increase the awareness of these actors about the energy savings opportunities in AC plant, from the easiest to implement energy conservation opportunity (ECOs), of which the energy impact can be assessed just by simple observation, to more complex actions that can be lead only after a specific study of feasibility in a detailed audit.

The educational level of the audience is supposed to be of post-high school at least. It is expected that the audience level of knowledge of AC is not very technical, they already know the basic principle of operation, but skills or competences possessed can be very different from an audience to another and their skills can be focused in a single aspect of the system (control, maintenance or use etc.). The TP is so devoted to this public but can be at the same time used in different scenarios: students with HVAC class (where rarely efficiency is related to already existing systems) or initiation of inspection technicians or auditors for example.

Scopes and structure of the TP
The aim is to give a large view on the AC systems and market to non expert public, who will be conscious through this package of the stakes of the AC energy use at **international** and **individual** level. Moreover, the TP illustrates to the public the content of the inspection procedures and can be used to initiate to audit methods.

Different modules realized with PowerPoint slideshows constitute the AUDITAC training package. The main discourse is developed around the audit but different annexed modules exist.
Thank to its modular structure, the content of the training can be adapted in function of the type of audience but a default path is suggested. This starts from the main module on audit, follows with the module on the European Energy Performance of Building Directive (EPBD) and inspection, continues through the module on systems recognition and classification and ends with the illustration of some examples and cases of AC auditing, as shown in Figure 3.

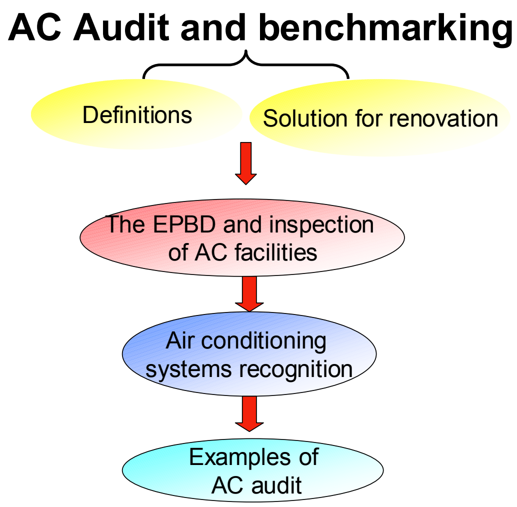

Figure 3: Structure of the training package with the main modules and the education path represented

The core of the TP: the audit module
The main module is divided in two parts. In the first part AC audit and benchmarking are defined. Firstly, the aim of the audit is defined in relation with the life of an AC plant: when it can happen and why, in relation and in parallel with O&M activities and in relation with commissioning. This part mean to mark the difference between audit and other activities such O&M activities in which the main function of the system is maintained but not it's efficiency.
The auditor has to preliminary understand and take into account the requirements of the building in terms of Air Indoor Quality (AIQ) and occupancy scheduling. The main audited aspects of the system linked with the building in the AC audit are: equipment defects, cooling loads, actuators and sensors, control strategies, operation and maintenance activities.
Therefore, the air conditioning benchmarking method is detailed. Benchmark is a useful tool for first find out the most energy consumption system but care is needed to use it. The best way of benchmark energy consumption or capacity installed is to parameter the benchmark following several criterions: sector, type of system, IAQ required.
Audit shouldn't be anymore a black unknown box to the AC facilities owner: after dissipating the mystery of the audit content and make highlight on its objectives and advantages, they will be aware of the opportunities and profitable actions in a transparent procedure.

In the second part a typical procedure for audit is described and the attention is on the solutions that audit can propose. Energy conservation measures are listed for different systems with some example that allows to quantify the effectiveness of a solution in some detailed case.
Opportunities for replacement of obsolete equipment by present equipment are evaluated through the evolution of the average system performances (performances benchmarking) on the last two decennials in order to help for decision of punctual improvements or a whole replacement.

At the end of the module the public is aware of the complexity of the AC facilities audit and about all the aspects more or less obvious that have to be included in the audit. He has been softly introduced to the audit techniques, starting from the benchmark tool then, increasing the complexity, into a typical complete audit procedure.
Finally, the public is lead in the more delicate phase of the audit: the decisional process for the more common and profitable energy conservation opportunities. In this process he is guided and supported by examples and quantitative indicators that allows to understand the global approach in economic and energy terms.

Auxiliary modules
Once, acquired the main definitions and the global approach of the audit explained in the first module, on one side, auxiliaries modules are added with notions that can be missing for some audience as a complement of the main modules, on the other side, a more applicative module immerses the audience in real situation, guides them into the audit on field and put them in front of a variety of cases with their successful audit results.

The first annexed module is on the European panorama of AC. A survey of the AC market in Europe actual and forecasted is showed. Through this information, the auditor is pushed to think about the energy stakes in the AC market, focusing on the most used technologies in general and in different sectors. The data are mainly extracted from the EECCAC study [EECCAC, 2001].
Then the new articles introduced by the EPBD that concern AC are listed: mainly the article 3 about building energy performance certification and article 9 on inspection of the air conditioning facilities. For the last measure, a CEN standard has been developed. The details of the text of the standard are listed and commented, in order to rise the awareness of the audience on the characteristic of the inspection they will pass through, and compare the aspect considered in the inspection with the detailed action of the audit procedure. The main message is how to best profit from these two procedures that cant' be exchangeable but can be profitably complementary and subsequent.

A second complementary module is developed including a part of the air conditioning technical module of the GreenBuilding programme [GreenBuilding Programme]. In this section of the training package the large variety of AC system types is described and it includes a simple method to help in the system recognition when information is missed. The method is based on easy visual observations of the system components and fluid networks.

A third module tests the notions acquired in the first module through simple example and exercises where common situations are showed with the more adapted energy conservation actions implemented. Some time the case is presented as an interactive exercise where the audience can use the knowledge developed through the other modules to choose the more adapted solutions. Emphasis is put on the energy aspects for each exercise and sometime conversion in money savings can be performed.

Conclusions
In this paper we showed some results from the AUDITAC project. The AC audit is showed to be an important and necessary step in a plant lifetime.
The features of the AC audit methods have been described through two levels of complexity: the pre-audit and the audit methods.

For pre-audit, the elements of the procedure are listed with accent on the scope and the limits of each task. These steps are:
- Preliminary Data Collection
- Analyzing energy data
- Looking at loads fir cooling
- Building profile
- The site visit
- Analysis and reporting

From the pre-audit conclusions more detailed actions can be undertaken in audit to quantitatively determine the energy savings. Four main aspects have to be considered in the decision of renovation and have be considered in detailed audit:
- Verification of system performance
- O&M for energy efficiency
- Retrofit
- Improvements through BEMS.

Finally, a training package about air-conditioning audit has been presented. This tool has been created to prepare and introduce air conditioning actors (energy managers, facilities owners, technicians related to AC etc…) to the compulsory inspection and to disseminate the advantages and opportunities that the subsequent audit can give.
The TP structure is modular and can be adapted to the audience. The default path of education starts from general definition of audit and benchmark then presents a typical audit procedure and the more profitable energy conservation opportunities in AC facilities with quantitative indicators.
Auxiliary modules are added. The first is about the Energy Performance of Buildings Directive (EPBD) articles concerning air conditioning and the AC inspection. Another module shows the large variety of AC systems and a simple method for system recognition. The last module is an interactive module with exercise and example in order to test and set up the knowledge developed in the previous modules.
Basically, the TP has been designed for a public with an educational level of post-high school and can be used in different scenarios (students with HVAC class, inspection technicians, energy managers' information etc…).

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About the audit of air conditioning systems: Customer advising with the help of case studies and benchmarks, modelling and simulation

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Abstract

Article 9 of the European Building Performance Directive impose the inspection of air-conditioning plants above 12kW. Therefore, tools will be needed by the auditor or inspector. The purpose of the audit of a HVAC system is indeed to advise the customer about the energy performance of the system and to suggest modifications and improvements to be carried out. Different levels of audit are possible, ranging from a basic observation of the energy bills up to more advanced approaches involving realisation of measurement campaigns and advanced calculations. In this respect, modern simulation tools are a valuable resource that can help in improving the information gained from the audit. Such tools can be used at two levels in the context of an audit. First, upstream of the audit procedure in order to calculate the expected performance of a given system or of a family of systems. This process is called “benchmarking” as its objective is to provide reference performances for the system under investigation. This approach efficiently relies on the information gained from Case Studies. Then, simulation can be used during the audit procedure in order to complement the information obtained from observation or measurements and to extrapolate the performance of the system and, more important, the change of performance which could be obtained by submitting the system to some modifications (in the design and/or in the operation).

This paper outlines such an approach as developed inside the AUDITAC project (funded by the European Union under the “Intelligent Energy for Europe” program). It addresses the different aspects of the analysis: selection of case studies and use of information obtained from this analysis; calculation of benchmarks including presentation of the different simulation models used in that context; integration of those elements in an advising method or tool devoted to the information of the customer. This customer advising tool is one of the deliverables of the AUDITAC project.

Introduction

The “Customer Advising Tool” is one of the main deliverables of the AuditAC project. It is based upon the lessons obtained from a selection of Case Studies and on benchmark performances calculated by simulation models. This tool is devoted to the audit and inspection of A/C systems, from the viewpoint of both the customer or the inspector. It is a tool that is considered of great importance to make the auditing procedure more efficient and able to produce results in line with the requirements of the

European Building Performance Directive. This paper presents the current status of this deliverable of of the AUDITAC project as well as that of its different components. .

The paper will focus on the method proposed to produce the benchmarks and on the different simulation models that are required in the benchmarking operation. The relations between the benchmarking operation, the case studies and the advising tool are highlighted in the paper.

General presentation of the Customer Advising Tool

The (ambitious) objective of the audit of a HVAC system is to advise the customer: the auditor has to tell the customer what might be done, and for what cost, in order to improve the energy performance of an existing HVAC system.

The AUDITAC project hopes to bring this dream much closer to reality, through some practical tools developed in the European "AUDITAC" project. These tools include:

- A Case Studies centred database
- An advising method, and
- A set of performance benchmarks.

The focus of AUDITAC is on the use of air conditioning in *cooling* mode only. Heating is not addressed in this project.

In deciding the form that the AUDITAC advice should take, consideration was given to the very first question that an audit or inspection should answer, which is 'Is the building under consideration in need of an audit?' One of the main aims of the AUDITAC project is to produce information in the appropriate form to answer this question quickly and efficiently.

A positive answer could be arrived at if the following facts apply to the A/C system and/or building under consideration:

- The HVAC is not providing correct control of indoor air quality (IAQ), indoor temperature and/or indoor air humidity.
- The running costs and/or the environmental impacts are excessive or unacceptable in terms of peak power, energy and fluid consumptions, maintenance and reparation costs, environmental impact, safety, etc

The advising tool under development by the AUDITAC project will synthesise the best aspects of the various current or proposed A/C inspection methodologies in Europe. The aim is to produce a tool which will lead the user through a methodology tailored to meet the situation they face in a particular building.

The heart of this tool is proposed to be the database, which contains Case Studies of real actions undertaken in real systems, and the savings that were obtained. The database also contains the results and findings from modelling exercises undertaken on the various system types, right down to component level.

Using the tool to tailor the methodology to the actual system to be inspected/audited, will enable both building/system owners and experienced inspectors to, amongst other things:

- Identify the A/C system types they have installed in their buildings
- Identify the specific equipment installed, through linking into the information available from Eurovent
- Identify whether the A/C systems installed meet typical benchmarks for that type of system.
- Identify whether the system as installed appears to have room for improvement, and where that improvement might be made.
- Identify the common defects to be found for the identified A/C system type, typical remedies, and the typical energy and cost savings to be made from rectifying the defects.
- Identify real world Case Studies which have achieved energy savings in systems and buildings related to the situation being audited.

The tool is intended to be designed to minimise the time taken to appraise a specific situation by removing all guidance which is superfluous for that situation, and by then leading the user through a methodology designed to provide as much useful information as quickly as possible.

It is anticipated that the tool will be both web-based and downloadable, to enable it to be run as a stand-alone programme on a laptop while on site.
With respect to the available and on-going developments which are taking place in the field of audit, this particular approach intends to bring the latest developments of building and HVAC simulation at the benefit of the auditor. So much progress was indeed performed in the last years to make modern and efficient simulation tools reliable and easier to use in a design or operation context that it would be a pity not to transpose this body of knowledge in the audit field. For instance, efficient use of building and HVAC simulation allows to better identify the terms of the energy balance of a building or of a system in this building. It can also be used to predict, with an increasing level of accuracy, the consequences of a given choice: replacement of a component, modification to the control strategy,…

The Case Studies database

Answering the question of the need of an audit and also going further in the audit procedure requires some strong references. Case Studies will help a lot if they are made reliable; to this end the documentation of each Case Study must contain sufficient information to allow the user to transpose it to their specific problem (specific building, specific climate, specific occupancy, specific requirements and specific HVAC system).

Simulation models are a vital part of the methodology behind the Customer Advising Tool. In fact, there is always some (implicit or explicit) simulation behind any of these “transpositions” and “adaptations”. For example, assuming that some energy performance improvement can be transposed from one to another case is, de facto, a (basic) simulation.

To enable an appraisal of how a system might be improved requires entering some details of the (sensible and latent) cooling demands and of the air conditioning process actually used.
However, to make this part of a general methodology requires great care as there are, along this way, a lot of traps:

- There is no simple relationship between the cooling demand and the climate;
- Actual building occupancy is never well defined and it has a big impact on the cooling demand;
- The majority of so-called “air conditioning” systems are actually not able to achieve all the three air conditioning requirements (IAQ, indoor temperature and indoor humidity);
- A large percentage of existing air conditioning systems were never correctly balanced,or commissioned, and are rarely well maintained;
- In many cases as well, the full control and management potentials were never used and no optimisation has ever been performed;
- Users requirements and complaints are poorly, or never, recorded. So it is difficult to assess what the potential problems might be from a time limited survey.

The last point (uncertainty about requirements and complaints) adds greatly to the complexity of the advice to be provided. How are we to compare the energy consumptions of two systems, if they are not achieving the same comfort level? How is it possible to convert a violation of comfort requirement in “equivalent” energy terms?

Figure 1 shows the general approach which is proposed for the use of case studies in the Customer Advice context.

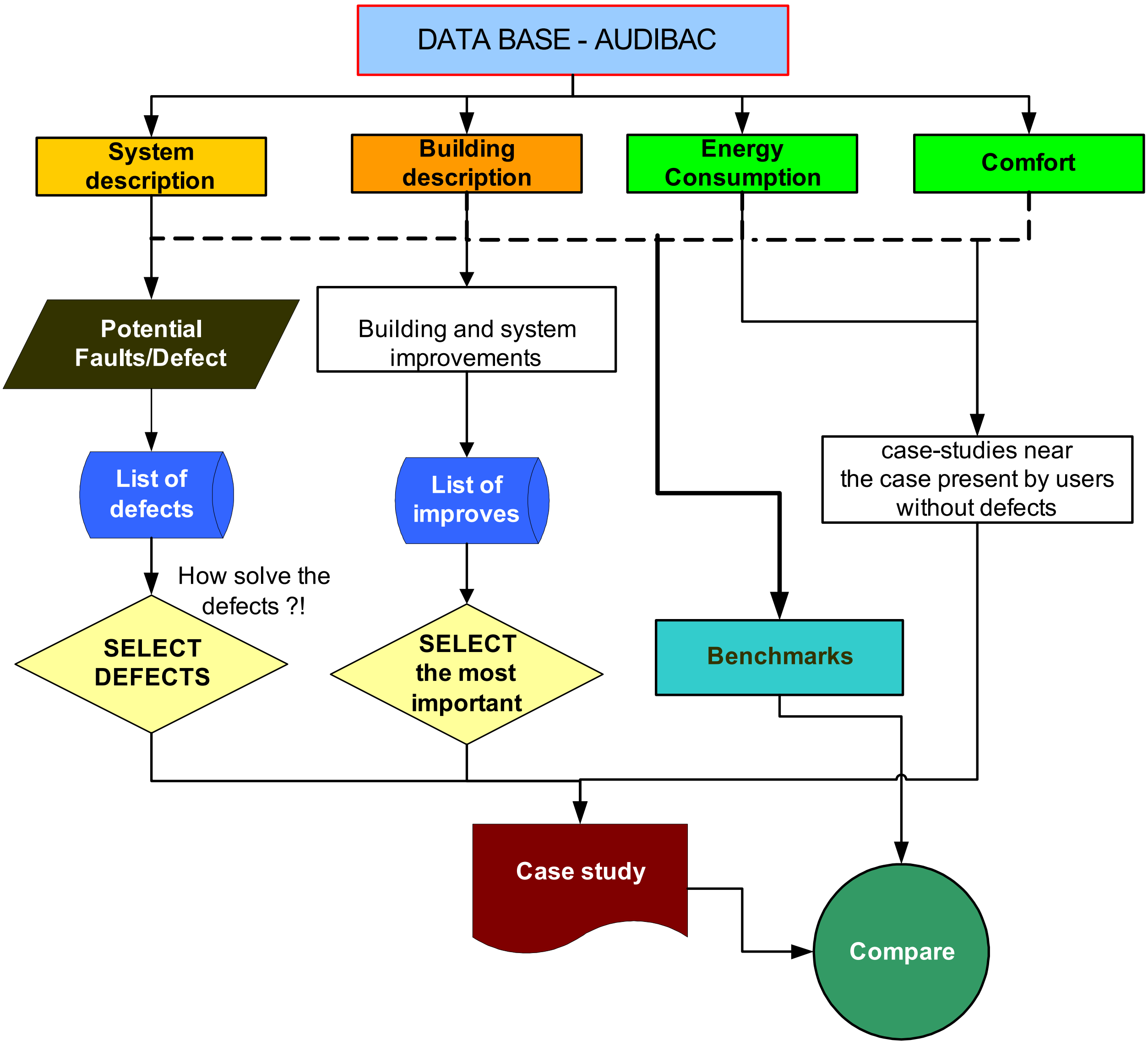

Fig. 1: How to use the case studies database in a Customer Advising Context.

The database contains information about the building and the associated system.Therefrom, a list of potential defects and improvements may be identified. The database also contains information about energy performance and thermal comfort. In a typical Customer Advising process, the first step consists in finding in the database a corresponding case to which the building submitted to the audit can be compared. Different variations to the reference(ie existing) configuration can be simulated, either during the audit process or a priori for the examples populating the database.

About benchmarks

The impossibility of describing all possible situations that might be encountered during an audit means that we have to try and find a means of describing what constitutes good, average and below average energy performance across a range of situations.

Benchmarks are therefore a vital part of the advice to be generated, but they need to be seen to be reliable and adaptable to the specific case considered.

Generation of benchmarks

When starting an audit procedure for a building, the auditor is likely to have to collect a number of items information about the building to be audited (building fabric, HVAC system, occupational regime, weather data,…).

The auditor also needs to have an idea of the energy consumption of the building (including its disagreggation to a certain extent) in order to be able to compare the current performance of the building to a reliable “reference” or benchmark. Disaggregation can be achieved according to the different energy sources considered (gas, electricity,…) and/or according to the forms of energy use: heating, cooling, domestic hot water, auxiliary consumption…

Establishing benchmarked performance is not an easy task, as the energy consumption of a building can never be analysed without looking at the same time at the real services provided by energy, i.e., in the present case, occupants comfort.

When speaking about comfort, we are facing a very complex reality: this issue does not only concern *thermal,* but also *acoustic* and *visual* comfort and possibly other aspects. In so-called “thermal cooling” comfort, three basic requirements have to be fulfilled simultaneously: temperature, humidity and air quality. When auditing a building, the observed energy consumption has always to be analyzed with respect to the real (and consequently also observed) achievements of the requirements.

To establish suitable benchmarks for the range of building and A/C system types considered by the AUDITAC project, the crucial question to be answered is: what should be the range of consumption(s) for such buildings and A/C systems, in such a climates, with such occupancies, such internal loads and such actual indoor environments?

Given an audited building is not necessarily achieving a perfect comfort, the benchmarks could theoretically be obtained in two ways:

1) By calculating the consumption of reference (ideal) systems achieving the same level of (non-perfect) comfort as exists in the buildings surveyed;
2) By calculating the consumptions that a range of actual systems would have achieved if respecting their comfort requirements, and then comparing these with a calculated value for the corresponding reference systems.

The first approach is easier, but it doesn’t reach the final objective: may be the system is not consuming too much, but it’s still violating some of the requirements. In such case, some (comfort) retrofits would be required anyway.

Something in-between of the two approaches might be done: “bringing” the existing system to a minimum of IAQ and comfort, *before* comparing it some reference.

If comfort data are not available, establishment of benchmarks should only rely on energy performance, making the hypothesis that comfort is obtained, using therefore the following approach:

1. Assess how A/C systems in real buildings perform from an energy viewpoint (if possible, obtain published energy consumption data for the various building and system types by European region, where this information exists).
2. Model a subset of previously monitored buildings and systems to see what their theoretical performances ought to be
3. Using the findings from this part of the work, assess how accurately the models predict the real monitored performance, and which are the main factors that affect this use. Use this accuracy range as part of the benchmark ranges to be produced,
4. Model the buildings and systems for ‘ideal’ performance and set this as the unachievable upper performance range

5. Find out how the real buildings and systems performed as a percentage of this ideal figure and use this information to help set benchmark ranges for good
6. Apply the modelling approach to the range of building types, systems and locations to be covered by the project to establish benchmarks for different locations and building types as well.
7. Produce a range of benchmarks for the combinations considered, and establish where the boundaries for good, average and below average A/C system energy consumption performance figures should be set as a first attempt at providing these figures. They can always be refined in the future – the main thing is to get some figures that can be used to start with.
8. As well as having looked at the holistic building and system performance figures, we also need to have assessed how individual items in A/C systems can affect the overall performance of the system, i.e. model variations in system design to assess the effects of each change on the overall system performance. The findings from this analysis go into the database to help provide guidance on actions to be taken to improve performance.

As the objective of the Auditac project is to develop a Customer Advising tool, which afterwards should be used in a typical audit procedure, the calculation of benchmarks could be carried out at two different moments: (fig.1):
During the Customer Advising Tool development and at a rather "detailed" level, taking profit of an exhaustive availability of information and data about the building, the HVAC system, the occupancy profile, the weather…
This approach is applied to the case studies analysed within the Auditac Group; it's also required to assess the validity of the proposed auditing procedure (during the development phase of the method). Using the Case Studies, the conclusions of the approach will be summarized in a dedicated Customer Advising Tool. This tool will be developed around the Database summarizing information about the different Case Studies and could be connected to a simplified simulation tool developed as part of the benchmarking phase.
During the Customer Advising Tool utilization in a typical audit procedure and therefore at a "simple" (and quick) level, using incomplete information, in the frame of a short term procedure and nevertheless ending up with reliable (and exploitable) results. It is likely that the second approach is the only one the auditor will be able (given time and resources) to put into practice. The idea here is to use a rather simplified tool with only a few parameters to input (and consequently making use of "typical" default values identified as described earlier) but still able to provide sufficiently accurate results to make decisions about the system. To assess this accuracy, comparison will be carried out by applying both levels of calculation to a set of case studies for which sufficient information is available.

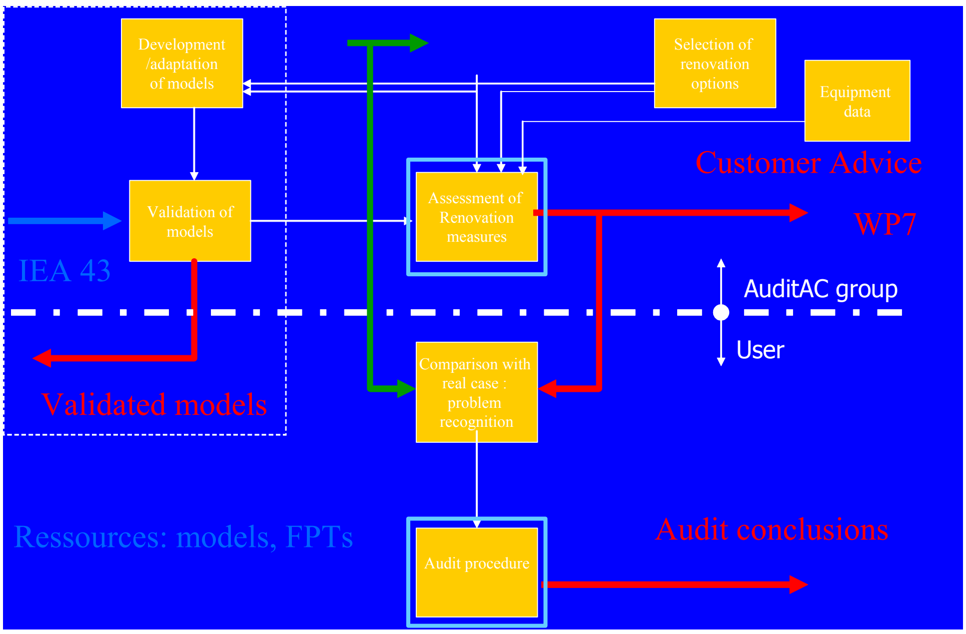

Figure 2: Connection between the two levels of analysis

Therefore, the issue of how to jump from the detailed level to the simple one is also emerging. To jump from one level to the other implies the following actions:
- population of the database: the Case Studies database should be sufficiently representative and include a variety of building types. The Customer Advising Tool should also take into account the weather dependency of the different renovation measures.
- association of the case which is the object of the audit to a sufficiently similar case in the database. In particular, the climate similarity/difference should be taken into account.

Another question which characterize the benchmarking operation is concerning the performance index which is used in order to compare the building subject to the audit and a reference case.

This performance index can be:
- The actual comfort conditions (in that case, the “reference” are the requirements);
- The building energy demand (reference = projected data);
- The Air Conditioning system energy consumption (reference = energy consumption of a comparable case)

These evaluations should ideally be carried out in sequence. Failure to fulfil the first condition makes the energy performance not representative. As mentioned above, the first “renovation” to be made in such a case is to change (estimate?), if possible, the operation of the system in order to achieve the design requirements. This could imply some additional energy use. A meaningful comparison to a benchmark energy figure can only be made under these improved conditions. This potentially implies a time lapse in the audit to allow the amended energy consumption to be assessed, but in reality the existing consumption is likely to be used to obtain an initial estimate of the energy performance of the system as it is currently operated. The audit may then identify a need for a further audit to take place at a future time to assess the true system performance.

Once the required comfort conditions are observed, then a comparison can take place between the theoretical demand of the building (A/C system?) and the measured demand. As mentioned above, end use demands are not very often directly measured in buildings.
If demands are directly measured, the interest of this comparison is to identify problems due to the building (lack of insulation, too high air renewal rate, etc…) independently of the system: for example, the building requires too much heating or cooling to maintain the comfort conditions. If measured demands for individual system components are not accessible, it is necessary to move to the next step where energy consumptions are compared. At this point, the measured consumptions are compared to the target defined in the building project.

If demands are not measured, an alternative option consists in calculating these demands using a simulation model of the building and cooling system.

Calculation of building demands
While, in an audit procedure, the field evaluation or identification of the end use of the building demand is not that straightforward (heat/cool counters are not very often installed in buildings), calculation of the theoretical demands of a building appears logically at the start of a design process as well as in an “a posteriori” evaluation procedure.

But, to calculate a “rational” cooling demand, with consideration to sensible and latent components and to corresponding temperature constraints, is a challenge. It is not simple to characterise the climate for the cooling requirements. Reference to outside dry bulb temperature and to corresponding degree-days or degree-hours does not correlate as well as for the heating demand.
Reference to wet bulb temperature or to enthalpy does not fare much better.

However, from another viewpoint, both sensible and latent cooling demands in commercial buildings are usually much less affected by building dynamics than heating, especially if the thermal mass is not accessible. A *steady state* balance model would therefore seem accurate enough in the audit context. So, rather than looking for a (very hypothetical) global weather index, similar to heating degree-days, it seems more rational to run a simulation model on a few thousands of hours, corresponding to one (or to several) cooling season(s). The current performances and capabilities of simulation tools make this approach very expedient. The climate can then be considered as it is, without any simplification.

The main simplifications are still welcome on the system (building + HVAC) side, in order to get calculation robustness, easy understanding and easy parameter identification.

The level of detail required for each calculation can be very different. For heating calculations, the major issues are a correct description of the building envelope and a reasonably accurate evaluation of the air renewal. For cooling calculations, the fenestration area and location, the level and distribution of the internal gains, the ventilation rates, the geographical location and the usability of the thermal mass (if present and accessible) appear as critical issues. Most of these issues are explicitly taken into account in current design and equipment sizing procedures.

In an audit procedure, where time and information are lacking, a more expedient method has to be carried out. For the AUDITAC project it is currently proposed that this procedure will be based on the use of “simplified” models, in which the description of the building is aggregated into a small set of parameters.

Although simplified”, the method has still to be able not only to evaluate the performance of a building as it is, but also to predict its potential performance after retrofit. Consequently, the simulation environment has to be “sensible” to those potential alterations.

The AUDITAC project has still to decide how these models will be described.

Calculation of energy consumptions
Introducing the HVAC system involves moving from building demands to building energy consumptions. Again, the issue is to find the optimal level of detail required of the model in relationship to the amount of information which is available for the audit. Again, two levels are possible:

- A rather detailed description of the main components of the HVAC system can be considered in the development process of the audit method.
- A less detailed approach can be used in the audit realisation. Basically, the different pieces of the HVAC system can be “represented” by their respective efficiencies.

The HVAC system model has to be designed in such a way as to make clear the different efficiencies usually considered by practitioners at the levels of control, emission, distribution, and generation. Those efficiencies are very integrated quantities by nature, but should still appear as parameters or as calculated output variables in more sophisticated models. The crucial issue, in the audit context, is to find models allowing the auditor to take into account (and to be sensible to) the main renovation options that are available in the AC system. An example of such a list was published by Washington State university [ ]

Examples of Simulation Models
Here follows the presentation of some models that might be applied (although the decision has not been taken yet within the AudiAC group) in an audit procedure.

In a classical design process, the calculations are run “up-stream”, i.e. from the air conditioned zones, towards the plant, passing successively through terminal units, air and water distribution and air handling units.

Most simulation programs are organized in the same way: passing progressively from building zones to global consumptions.

But this would not be an easy way to conduct an audit: the actual demand of each zone is usually very uncertain, mainly on short time periods.

In current practice, the auditor will have to “jump” from one part of the system to another one, according to the (always very partial) information available:

The initial information usually available is split between the “extremities” of the system, namely complaints expressed by the occupants, and running costs (energy and maintenance).

Various types of very friendly simulation models of are required to assist the auditor in interpreting this sort of information.

This “friendly” character has little to do with the number of equations involved or with the calculation time required. The bottle neck is not in the computer, but in the human brain: simulation hypotheses have to be fully transparent and the number of variables and parameters has to be reduced to an absolute minimum.

Simplification is essential here, but the (design) reference models can be used to generate the simplified models which are better adapted to the audit process.

Information available in “As Built” files (design and commissioning data) should be used for initial tuning of the models.

For some of the components, careful tuning of the models would even make it possible to use them as measuring devices.

A few examples of reference and basic models are presented hereunder and concern:

- a simplified building model compatible with an audit procedure
- a terminal unit model
- a pump and/or fan model

Very simplified building zone model
The following model is based on a very simplified steady state representation of heat and mass transfers and heat and mass balances inside the zone. It may help in checking and the measuring results.

Inside air quality (characterized by the concentration in some reference contaminant), air temperature (supposed here to be the same as globe temperature) and air moisture are the three selected output variables.

Only two parameters are here selected in order to characterise the zone: its envelope heat transfer coefficient and its “equivalent solar aperture”.

Four groups of input variables are considered in order to define all the “perturbations” imposed to the zone. They concern:

The occupancy loads

The outside climate

The ventilation

The “emission(s)” of the terminal unit.

This gives the following information flow diagram:

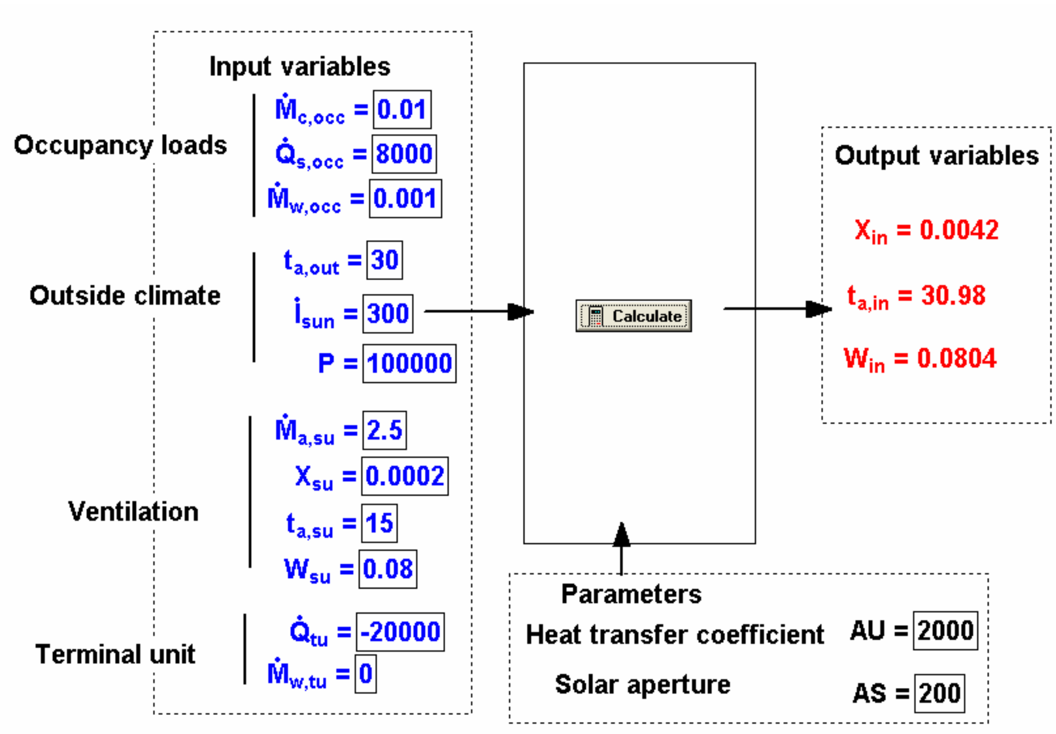

Figure 3: Block diagram of the simplified building model (EES software)

The following equations are used:

Steady state contaminant mass balance:

$$\dot{M}_{c,occ} + \dot{M}_{a,su} \cdot (X_{su} - X_{ex}) = 0$$

Perfect mixing hypothesis:

$$X_{ex} = X_{in}$$

Steady state sensible heat balance:

$$\dot{Q}_{s,occ} + \dot{Q}_{sun} + \dot{Q}_{fabric} + \dot{Q}_{tu} + \dot{M}_{a,su} \cdot c_{p,a} \cdot (t_{a,su} - t_{a,ex}) = 0$$

$$\dot{Q}_{sun} = AS \cdot i_{sun}$$

$$\dot{Q}_{fabric} = AU \cdot (t_{a,out} - t_{a,in})$$

$$c_{p,a} = \mathbf{Cp}\,(\text{'AirH2O'}, T = t_{a,su}, P = P, w = W_{su})$$

Perfect mixing hypothesis:

$$t_{a,ex} = t_{a,in}$$

Steady state water mass balance:

$$\dot{M}_{w,occ} + \dot{M}_{w,tu} + \dot{M}_{a,su} \cdot (W_{su} - W_{ex}) = 0$$

Perfect mixing hypothesis:

$$W_{ex} = W_{in}$$

According to specific needs, such a model is easy to complete, by introducing several adjacent zones, storage effects (in transient regime) and air transfer equation (infiltration-exfiltration in relationship with air tightness and pressure differences)…

Terminal unit used to cool a zone
The unit (for example a fan coil or a cooling ceiling system) is here considered as a semi-isothermal heat exchanger: the isothermal "fluid" is the indoor environment.
The two selected output variables are the cooling power provided to the zone and the fluid temperature at the exhaust of the unit.
The simplest approach consists in considering the unit as fully characterised by only one parameter: its heat transfer coefficient.
Three input variables have to be supplied to this model:The fluid flow rate, its supply temperature and the zone (air or globe) temperature.

This gives the following information flow diagram:

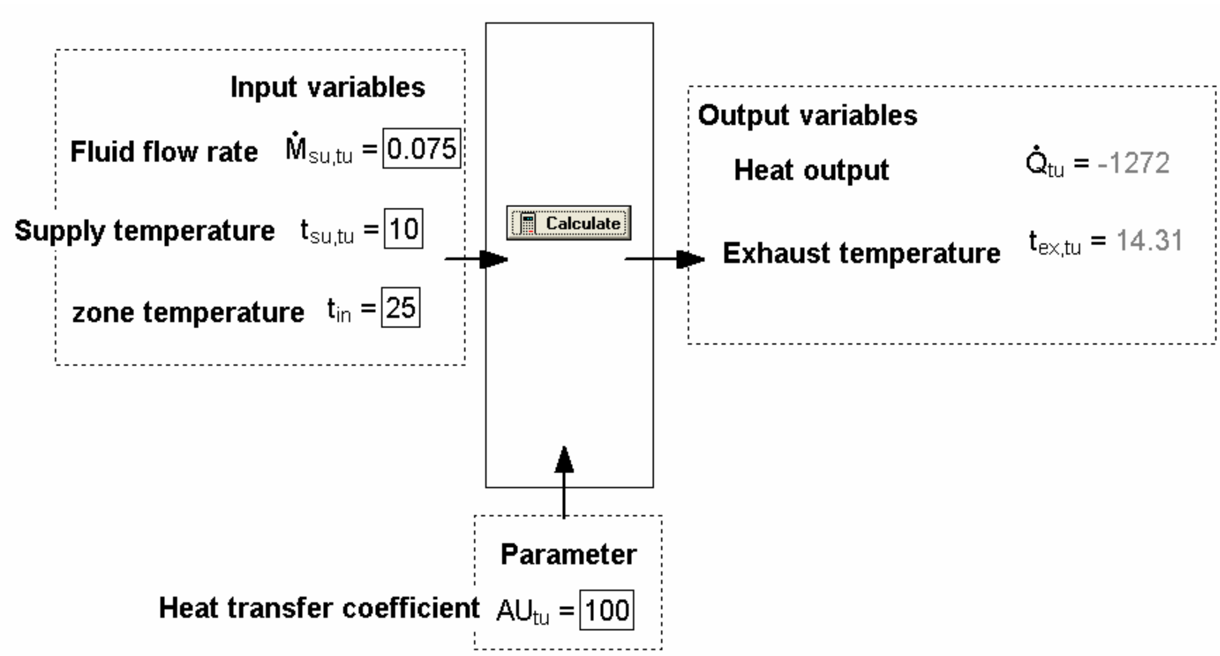

Figure 4: Block diagram of the terminal unit model (EES software)

The following equations are used:

$$\dot{Q}_{tu} = \varepsilon_{tu} \cdot \dot{C}_{tu} \cdot (t_{su,tu} - t_{in})$$

$$\varepsilon_{tu} = 1 - \mathbf{exp}(-NTU_{tu})$$

$$NTU_{tu} = \frac{AU_{tu}}{\dot{C}_{tu}}$$

$$\dot{C}_{tu} = \dot{M}_{su,tu} \cdot c_{tu}$$

$$t_{ex,tu} = t_{su,tu} - \frac{\dot{Q}_{tu}}{\dot{C}_{tu}}$$

Pumps and fans
Pumps and fans are currently modelled with the help of similarity variables: flow, pressure and power factors. These variables can be correlated to each other by polynomial expressions.
The example presented here is well fitted to the use of a variable speed fan as flow meter: the flow factor is calculated as function of the (total) pressure factor.

The main output of this model is the flow rate expressed here in "specific" value (in kg/s of *dry* air), as usually in air conditioning. Other outputs are: flow rate and pressure factors, exhaust air speed, total pressure difference, isentropic power and isentropic temperature increase across the fan (these two last outputs can be used as checking information).

The fan is supposed to be characterised by the diameter of its impeller (scale variable), the exhaust area and the coefficients of the polynomial correlation.

Supply air conditions (temperature, pressure and moisture content), rotation speed and *static* pressure difference are taken as input variables.

This gives the following information flow diagram:

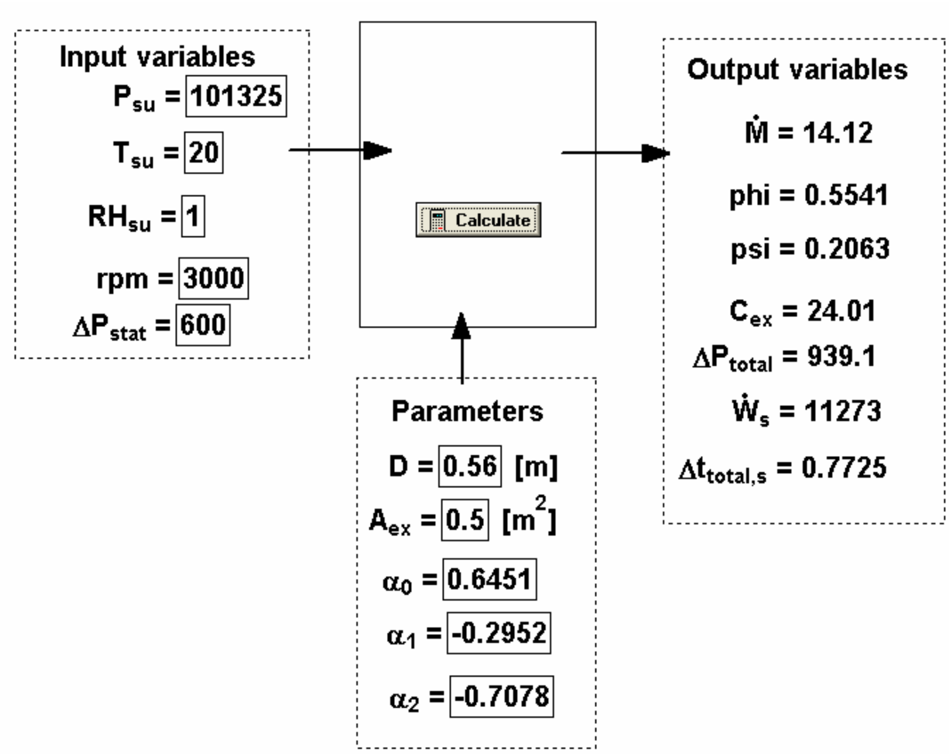

Figure 5: Block diagram of the pump/fan model (EES software)

The equations of this model are built on the basis of the definitions of two (flow and pressure) similarity factors:

$$\phi = \frac{\dot{V}}{A \cdot U}$$

Reference area:

$$A = \pi \cdot \frac{D^2}{4}$$

Peripheral speed:

$$U = \pi \cdot D \cdot N$$

rotation speed:

$$N = \frac{rpm}{60}$$

Pressure factor:

$$\psi = \frac{\Delta P_{total}}{P_{dynam,periph}}$$

$$\Delta P_{total} = \Delta P_{stat} + P_{dynam,ex}$$

Two dynamic pressures are considered: one at the exhaust and the other one at the periphery of the impeller:

Exhaust dynamic pressure:

$$P_{dynam,ex} = \frac{C_{ex}^{\ 2}}{2 \cdot v}$$

$$C_{ex} = \frac{\dot{V}}{A_{ex}}$$

Peripheral dynamic pressure:

$$P_{dynam,periph} = \frac{U^2}{2 \cdot v}$$

The following polynomial expression is used to calculate the flow factor in relationship with the pressure factor:

$$\phi = \alpha_0 + \alpha_1 \cdot \psi + \alpha_2 \cdot \psi^2$$

The following variables are then defined:

Specific mass flow rate:

$$\dot{M} = \frac{\dot{V}}{v}$$

Fan isentropic power:

$$\dot{W}_s = \dot{V} \cdot \Delta P_{total}$$

Air isentropic heating-up:

$$\Delta t_{total,s} = \frac{\dot{W}_s}{\dot{C}}$$

Air capacity flow rate:

$$\dot{C} = \dot{M} \cdot c_p$$

Conclusions

This paper has presented the current status of the customer advising tool as developed inside the Auditac project. To generate this tool, different resources are required: a case studies database in order to store, organize and allow retrieval of useful information concerning a given project; a set of benchmarks to locate the performance of the building under audit with respect to the expected performance. To calculate this expected performance, simulation tools can be used as they offer the capability of calculating the performance of a given project when submitted to some modifications and to provide, at the end, a useful information to the customer: what will be the benefit (in energy and/or financial terms) of the application of such improvements in a specific project? To provide the resources to answer such a question is one of the objective of the Auditac project.

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Impact of climate change on energy demand in the Swiss service sector - and application to Europe

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Abstract
The short-term dependency of energy demand for space heating on winter temperature in the Swiss commercial sector is well understood. This provides a basis for estimating the effect on demand of longer term changes in temperature, such as those reported for the period 1970-2003 (Hofer, 2003) and the further warming of several degrees C expected in the coming decades (Hohmann/Neu, 2004). Energy demand for space cooling is at present small and variations in summer temperature are hardly detectable in the national electricity demand pattern. But due to higher internal loads, fashionable glass facades and increasing comfort levels, the cooled floor area is steadily increasing. Events like the summer of 2003 are accelerating this trend and the specific energy demand for cooling. It is important, therefore, to develop a better understanding of the relationship between summer weather conditions and energy demand for cooling.
In this paper we explore possible changes in heating and cooling demand in the Swiss commercial sector over the next 30 years, taking account of the expected temperature increase and the evolution of the stock of buildings and their equipment. Two principal scenarios are evaluated: a reference case in which temperatures remain constant; and a second case in which temperatures increase. For heating demand, changes in specific energy consumption are evaluated; for cooling demand, specific energy demand and floor area equipped with cooling equipment are varied.
Although the principal focus of the work is on Switzerland, it is possible to extend the analysis to other parts of Europe. Energy consumption data for the commercial sector is sparse, particularly for cooling, but simulations have been used effectively in this context. (Adnot et al., 1999 and 2003). For much of Europe, we conclude that likely increases in cooling energy demand due to global warming will be outweighed by reductions in the need for heating energy. There is likely to be a net increase in demand for electricity in all but the most Northerly countries, however, and in the South a significant increase in summer peak demand. Depending on the generation mix in particular countries, the net effect on carbon dioxide emissions may be an increase even where overall demand for delivered energy is reduced.

1. Introduction
The short-term dependency of energy demand for space heating on winter temperature in the Swiss commercial sector is well understood. This provides a basis for estimating the effect on demand of longer term changes in temperature, such as those reported for the period 1970-2004 (Hofer, 2003) and the further warming of several degrees C expected in the coming decades (Hohmann/Neu, 2004). Energy demand for space cooling is at present small and variations in summer temperature are hardly detectable in the national electricity demand pattern. But due to higher internal loads, fashionable glass facades and increasing comfort levels, the cooled floor area is steadily increasing. Events like the summer of 2003 are accelerating this trend and the specific energy demand for cooling. It is important, therefore, to develop a better understanding of the relationship between summer weather conditions and energy demand for cooling.

In this paper we explore possible changes in heating and cooling demand in the Swiss commercial sector over the next 30 years, taking account of the expected temperature increase and the evolution of the stock of buildings and their equipment. Two principal scenarios are evaluated: a reference case in which temperatures remain constant; and a second case in which temperatures increase. For heating demand, changes in specific energy consumption are evaluated; for cooling demand, specific energy demand and floor area equipped with cooling equipment are varied.

The first part of the paper (energy demand in Switzerland) is largely based on the ongoing elaboration of new energy scenarios for Switzerland (Aebischer/Catenazzi, 2006). Two of the authors (BA and GC) acknowledge the financial support of the Swiss Federal Office of Energy.

2. The reference scenario

2.1 Brief description of SERVE04
SERVE04, CEPE's energy demand model for the service sector developed in the nineties and used on behalf of the Swiss Federal Office of Energy by CEPE in the current elaboration of new energy scenarios for Switzerland, is described in detail by Aebischer et al. (1996) and Aebischer (1999). The structure is mainly a widely-used bottom-up approach (figure 1).

$$\text{energy} = \sum_{i\,k} \text{quantity}_{i\,k} * \text{specific demand}_{i\,k}$$

i, k : economic sector, sub-sector, energy vector

- quantity : floor area (t, t', t'')
- specific demand : energy demand per m^2 (t, t', t'')

t, t', t'' : year of construction, year of 1st and 2nd refurbishment

Figure 1. Bottom-up approach used in the energy demand model SERVE04

For the electricity demand this simple approach is extended to include the observed increase of electricity demand due to structural changes within the economic sub-sectors (Aebischer/Spreng, 1994; Aebischer et al., 1994). Wherever possible this observed increase in electricity demand of 1,5% per year on average due to structural changes inside the sub-sectors is accounted for in the model by a relative increase of activities (floor area) characterised by higher specific electricity services. Examples of activities with higher electricity services are the modern retail stores with a large assortment of deep frozen food displacing more and more traditional corner shops ("Mom and Pop" stores) or large office buildings (with mechanical ventilation) including staff canteen and server room. In sub-sectors where this structural change could not be accounted for by changes in specific activities we assume an ongoing increase of electricity demand due to this structural change, but the increase of 1,5% per year observed in the eighties/early nineties is adjusted in proportion to the ratio of the actual increase of value added to the increase of value added in the eighties/early nineties. The observed electricity demand 1990-2004 in the Swiss service sector is rather well described by this model.

2.2 Major assumptions and inputs for the reference scenario

Conditioned floor area for heating and cooling
Reference floor areas are given 1990 to 2035 by Wuest&Partners (2004) for typical buildings (offices, schools, hospitals and others). CEPE used these areas and estimates of the projected number of full time equivalent employees compiled by Ecoplan (2005) to assign areas to economic activities. Overall conditioned floor area is estimated to rise by 26% between 2005 and 2035 (i.e., averaging 0,7% per year). The largest increase is in the health and remaining sectors (31%), followed by trade (24%), and the lowest in the banking and insurance sector. The growth of floor area is to a large extent due to the increase in floor area per full time equivalent employee, which rises between 2005 and 2035 by around 23%. Assuming that the relationship between employed persons and full time equivalents develops as in the years 1991 to 2003, the area requirement per employed person increases by 9% from 2005-2035.

Heating heat requirement in new buildings
The average heat requirement in a typical new service sector building was assumed to reduce at an annual rate of 1,8% per year, following that of multi-family houses (Hofer, 2005). This rate of improvement is based on the expectation of steadily reinforcement of building standards by the cantons and of the uptake of low energy buildings.

Energy efficient refurbishment
Based on consideration of 25-year refurbishment cycles of building components starting in 1980 and considering that only 50% are energetically improved (Jakob/Jochem, 2004), it was calculated that the annual rate of refurbishment affected 1,9% of total floor area in the late 1990s, reducing to 1,3% in the year 2035, by which time 72% of the floor area existing in 1980 would have been fully refurbished at least once. This was calculated to result in an average reduction in energy requirements of 50 MJ/m^2 per refurbishment cycle.

Heating system efficiency
The average efficiency of boilers was calculated to increase from around 73% in 1980 to around 98%, for gas-fired boilers, and around 94%, for oil-fired boilers, in 2035. This was calculated using the results of a study by Jochem/Jakob (2004), carried out in co-operation with representatives of the oil and gas industries.

Sources of heat in new and existing buildings
In 1985 approximately 70% of the total floor area in the services sector was heated by oil. In new buildings that proportion had dropped to around 40%, about the same as for gas. By 2035, the oil heated proportion is expected to decline gradually to around 35% and all other sources of heating to rise, except for electrical resistance heating. The proportion using heat pumps is expected to double between 2005 and 2035. In existing buildings, fuel oil is being replaced at a rate of rather more than 1% of total oil heated floor area per year, particularly by natural gas and wood, while electrical resistance heating is predominantly being replaced by natural gas and heat pump heating systems.

Structural change within economic sub-sectors
The impact on electricity demand of the structural change within the sub-sectors is (wherever possible) accounted for by the changing distribution of buildings characterised by varying electricity services. The evolution of the distribution of these buildings in the period 1980 to 2000 was chosen in such a way that the estimated increase of electricity demand by the structural change was reached. Future values are derived by assuming a continuation of trends in social and economic development since the 1980s.

Electricity demand in new and refurbished buildings
Target electricity consumption in new buildings is generally between 20% and 40% below the average in existing buildings of comparable functionality. Starting from the year 2000 these targets reduce by 0.5% annually. In the year 2000 roughly 20% of the new buildings reach these targets. It's assumed that this ratio reaches 35% in 2010 and 80% in 2035. For the refurbishment of existing buildings, it is assumed that half of the reduction in the new buildings is reached on average. Refurbishment is expected to take place at a rate approaching 4% per year, which is twice as fast as that assumed for refurbishment of the building shell.

2.3 Energy demand in the reference scenario

Energy demand for room heating, warm water preparation and some process heat is steadily declining by about -0,2% per year resulting in 2035 in a reduction of -6% compared to 2005. On the contrary, electricity demand is growing at a rate of 0,9% (figure 4). The demand in 2035 is 32% higher than in 2005. The electricity produced in Switzerland is quasi CO_2 free. Under the assumption that this is still the case in 2035, then the CO_2 emissions of the service sector are declining faster than the heat demand, mainly due to the substitution of oil by gas and other energy carriers. In 2035 the reduction reaches -17% with respect to 2005.

3. The climate change scenario

We investigate the energy effects of continuous global warming, defined by the climate change scenario. The various political and socio-economic reactions that accompany continuous global warming over the next thirty years are beyond the scope of this sensitivity analysis. We assume that the societal, economic and technical circumstances and developments remain unchanged from our reference scenario. It is also not feasible to investigate the effects on the many end uses of energy and electricity. For the purposes of this paper, we focus on the two most obvious and likely most sensitive areas, heating and cooling.

3.1 Weather characteristics under the climate change scenario
Temperature and radiation are used to describe the weather under continuous global warming conditions. We assume the following increases of the average daytime temperature and radiation:

- +1 °C in the months from September to May,
- +2 °C from June through August,
- +5% solar radiation.

For the years 2005-2035 we apply a linear inter-/extrapolation.

3.2 Demand for heating energy under the climate change scenario
We use the correction factors calculated by Hofer (2005) to quantify the effects of these new weather data on the demand for heating energy. These factors are based on degree days[1] and radiation values. This method is the same as correcting for the average of observed historical energy demand under variable weather conditions. Hofer produces correction factors for twelve building types.

The increase of the average daytime temperature by 1°C from September to May and by 2°C from June through August leads to a reduction of average heating degree days of 11%, comparable to the very warm winter months in 1994.

The demand for heating decreases continuously compared to the reference scenario and by 2035 is 13% lower (figure 4), and the CO_2 emissions are accordingly lower as well. In this calculation, the inventory of buildings remains unchanged relative to the trend development.

3.3 Electricity demand for cooling under the climate change scenario
Before we can examine how much the electricity demand for cooling is affected by an increase in the average temperature and radiation, we must first estimate the electricity use for air conditioning under the reference scenario. For this, assumptions[2] about the cooled space and the specific energy use for air conditioning in the service sector must be made. Table 1 shows estimates of the floor area for different types of buildings and different economic sectors that are partially and fully air conditioned (cooled).

In order to estimate the cooled areas, we postulate that “high tech” areas tend to be fully air conditioned, while “medium tech” spaces tend to be partially air conditioned. This results in an estimate that of the total occupied floor area, 20% is fully and another 20% partially air conditioned, a plausible estimate when compared with those of other European countries. Offices show a significantly lower percentage of air conditioned areas than in 100 office buildings examined in detail in 1990. Of those 100 buildings, 24% (accounting for 40% of the area) were fully air conditioned, 28% (32% of energy-demanding space (EDS)) were partially air-conditioned, and the other 48% (28% of EDS) were not cooled at all (Aebischer, 2005). We expect significantly lower percentages for the entire office area within the service sector, since an unknown (but certainly large) number of office spaces are not situated within office buildings, but in other structures such as apartment buildings.

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[1] Degree days are calculated as the sum of the daily differences between a “base temperature” and mean external temperature. Different definitions of degree days are used by different authorities; the definitions used in this paper are given in section 4.

[2] There are no representative data for the service sector as a whole as to the air-conditioned space, the installed cooling capacity or the electricity requirements for cooling.

Table 1 . Fraction of heated floor area for different types of buildings and different economic sectors that are partially and fully air conditioned (cooled).

	2000	2005	2015	2025	2035
	Fraction of floor area				
Office buildings					
not cooled	47%	43%	33%	23%	14%
partially cooled	31%	35%	41%	48%	55%
fully cooled	22%	23%	26%	29%	32%
Retail stores					
not cooled	50%	47%	41%	35%	30%
fully cooled	50%	53%	59%	65%	70%
Hotels and restaurants					
not cooled	59%	55%	47%	39%	32%
partially cooled	30%	34%	40%	45%	51%
fully cooled	10%	11%	13%	15%	17%
Education					
not cooled	90%	89%	86%	83%	81%
partially cooled	6%	7%	9%	11%	13%
fully cooled	4%	4%	5%	6%	6%
Health care					
not cooled	65%	64%	62%	60%	58%
partially cooled	32%	33%	34%	35%	36%
fully cooled	3%	3%	4%	5%	6%
Other activities					
not cooled	50%	50%	50%	50%	50%
partially cooled	25%	25%	25%	25%	25%
fully cooled	25%	25%	25%	25%	25%
Total service sector					
not cooled	61%	59%	54%	49%	44%
partially cooled	20%	22%	25%	27%	30%
fully cooled	19%	19%	21%	23%	25%

Source: CEPE/Amstein+Walthert, CEPE

The specific electricity use for cooling (including chilling, control of humidity and pumps and fans used in distribution) in office buildings is based on the above-mentioned 100 office buildings. A special analysis (Aebischer, 2005) produced the following values:

- 23 MJ/m2.year (6.3 kWh/m2.year) for partially air conditioned office buildings,
- 96 MJ/m2.year (26.7 kWh/m2.year) for fully air conditioned office buildings.

These results correspond well to simulation calculations (Adnot et. al., 2003) for office buildings under similar climatic conditions (figure 2). As with the other technologies, we are assuming an “autonomous” annual reduction of the specific energy requirements by –0.5%.

For calculating the specific electricity use in the other building types and economic sectors, we apply Adnot’s (2003) simulation calculation. This leads to the following values (relative to the office buildings): trade = 129%, hospitality sector = 68%, schools = 100%, health sector = 116%, other sectors = 100%.

Based on these assumptions, the electricity requirements under the reference scenario for indoor cooling are shown in table 2.

Table 2 . Electricity demand for cooling (including de-/humidification and distribution) of the commercial buildings in reference scenario, in TJ per year

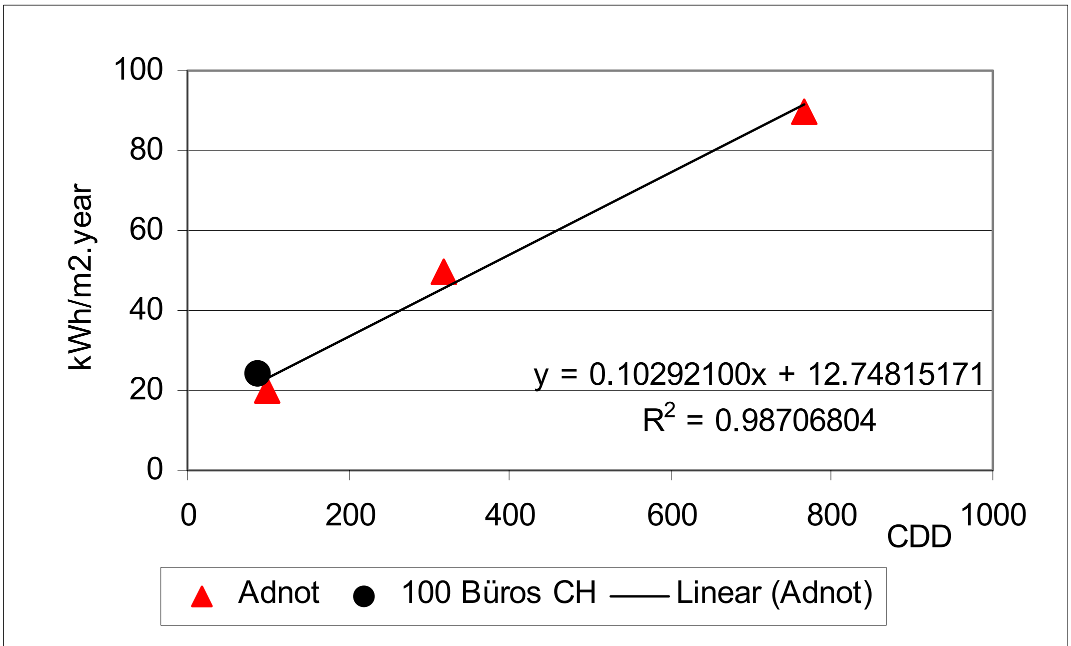
	TJ per year				
	2000	2005	2015	2025	2035
Office buildings	1062	1196	1465	1714	1922
Retail stores	1055	1173	1387	1561	1691
Hotels and restaurants	133	149	179	204	225
Education	116	138	181	214	238
Health care	198	222	262	297	326
Other activities	900	937	963	968	953
Total service sector	3463	3815	4437	4957	5356

Source: CEPE

The percentage of the calculated electricity requirement for air conditioning relative to the overall electricity use is 5.9% in 2000 and 6.5% in 2035. Relative to the electricity use for climate and ventilation according to SIA 380/4, it comes to 24% in 2000 and 26% in 2035.
In order to arrive at a value for the electricity requirements for cooling under the climate change scenario, two factors must be taken into consideration:

1. higher specific electricity use due to higher average temperature, and
2. rapid increase of partially and fully air conditioned spaces.

The fit of the specific usage values for cooling office buildings in London, Milan, and Seville, as simulated by Adnot (2003), to the Cooling Degree Days[3] (CDD) (calculated by Henderson (2005) for this study) results in a very good linear dependence: Electricity use = 0.1029*CDD + 12.7481. The empirical usage rate for the 100 office buildings in Switzerland lies very close to this line as well (figure 2).

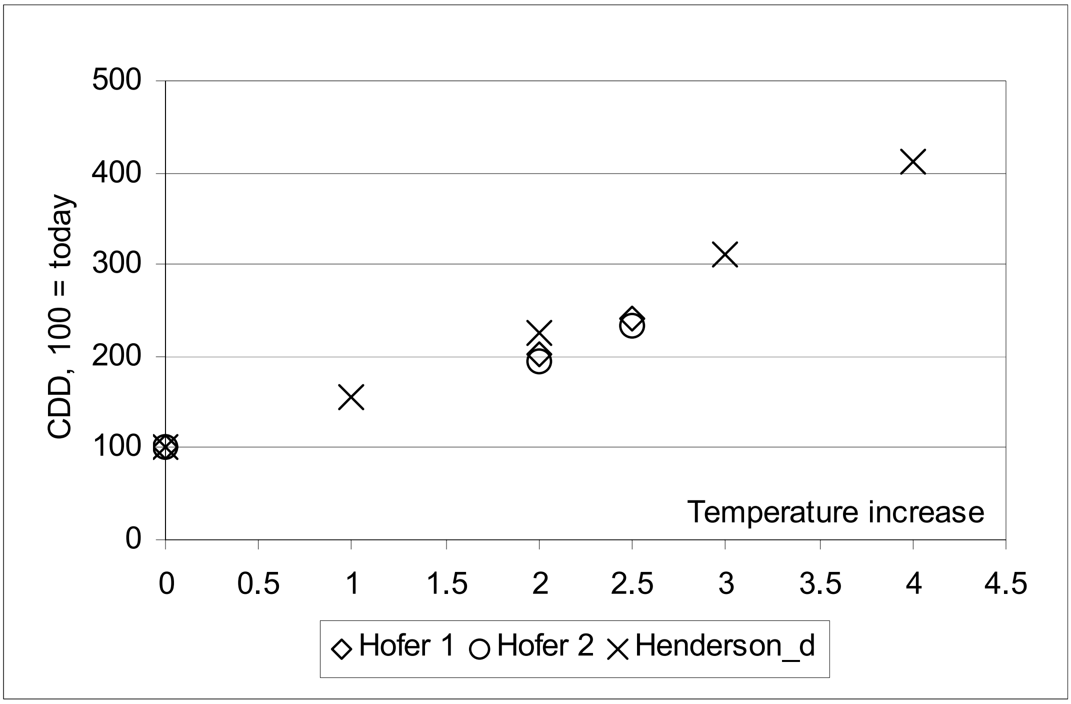


Source: Adnot, Henderson, CEPE

Figure 2. Electricity demand for cooling, in kWh/m2.year, of office buildings in London, Milano and Sevilla (= Adnot) in function of the Cooling Degree Days (CDD) in these locations. The linear fit of these three points is rather good R2 = 0.99. For comparison we show also the measured value of fully air conditioned office buildings in Switzerland (100 Büros CH).

[3] Calculated to a base temperature of 18.3°C

We also apply this linear dependence when calculating the higher electricity usage under the climate change scenario. Depending on the method used, it is possible to arrive at two different results when the Cooling Degree Days are calculated for a temperature increase of 1°C from September to May, and of 2°C from June to August (figure 3). For 2035 we use the average of the two values computed by Hofer (2005): An increase of CDD by 199% between now and 2035. Based on the above formula, specific electricity consumption due to higher temperatures is 46% higher in 2035. The increase in specific demand – relative to the reference scenario – is computed by a linear interpolation between 0 in 2005 and 46% in 2035.



Source: Adnot, Henderson, CEPE

Figure 3. Relative change of Cooling Degree Days (100 = mean temperature today in Switzerland) in the case that temperature increases in summer (June–August) between 1 and 4 °C.

The second factor, namely the rapid increase of partially and fully air conditioned spaces, leads us to the ad-hoc assumption that by 2035 half of the spaces that appear as non-cooled under reference scenario will be partially air conditioned. Further, we estimate that half of the partially air conditioned spaces under reference scenario will be fully so by 2035.[4]

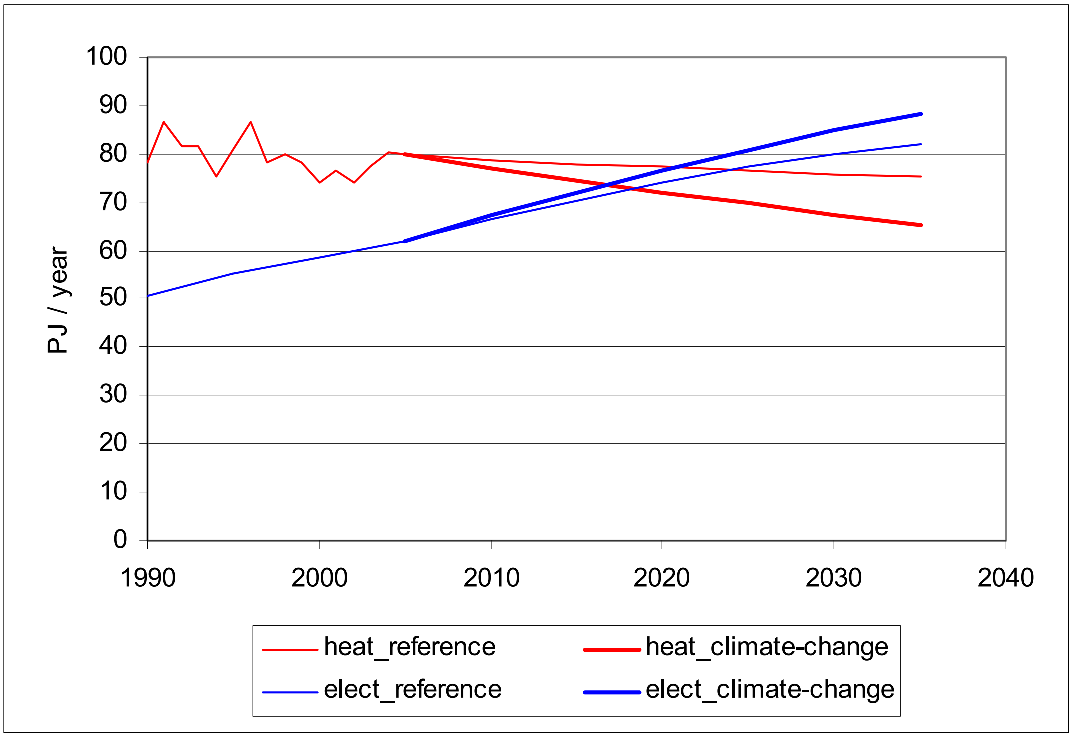
After determining these two factors, it is now possible to calculate the electricity demand for cooling under reference scenario_climate_warmer. Compared to reference scenario, we see an increase of 115% (table 3). Roughly 40% result from the higher specific requirements of the spaces that are already air conditioned under reference scenario. 20% are due to an increase of partially, 40% are due to an increase of fully air conditioned areas and the higher specific consumption for cooling these spaces relative to the trend scenario. The total demand is therefore 7.5% higher in 2035 (figure 4). In 2035, the percentage of electricity requirements for cooling as a part of overall electricity demand for the service sector grows from 6.5% under reference to 13.1% climate change. Relative to the electricity consumption for climate/ventilation according to SIA 380/4, the percentage grows from 26% under reference to 44% under climate change.

[4] This assumption was made together with Prognos AG which is coordinating the perspective studies. It is reasonable when one posits, as we do, that the climate change scenario refers to a continuous, evenly distributed temperature increase, and that there will not be another (or several) "Summer 2003" over the next few years. We believe that an accumulation of heat waves, even lasting only 1-2 weeks, would quickly lead to overall partial or full air conditioning.

Table 3 . Electricity demand for cooling (including de-/humidification and distribution) of the commercial buildings in climate change scenario and variation in 2035 relative to the reference scenario, in TJ per year

	TJ per year					Variation in 2035 relative to ref.
	2000	2005	2015	2025	2035	
Office buildings	1062	1196	1977	2972	4144	116%
Retail stores	1055	1173	1642	2126	2591	53%
Hotels and restaurants	133	149	268	416	592	163%
Education	116	138	341	591	881	270%
Health care	198	222	466	779	1149	252%
Other activities	900	937	1322	1744	2184	129%
Total service sector	3463	3816	6018	8628	11540	115%

Source: CEPE



Source: CEPE

Figure 4. Heating energy demand and electricity demand in the reference scenario with constant mean temperatures and in the climate change scenario with continuous increasing mean temperature and irradiation, in PJ per year

4. Implications for energy demand and CO_2 emissions in Europe

The approach used to evaluate impacts of climate change on energy demand for heating and cooling, described in detail the sections 3 for Switzerland, was applied to different climate zones in Europe. In this section we present the resulting impact on CO_2 emissions due to the climate change induced changes in heating and cooling demand in this different climate zones in function of two parameters:

- the fuel-mix for heating purpose and
- the CO_2 content of electricity.

Heating degree days (HDD) and cooling degree days (CDD) for mean climate conditions for the period 1961 to 1990 ("HDD_{mean}" and "CDD_{mean}") were calculated using temperatures obtained from

Meteonorm[5] for 8 European locations and for Florida, which is noted for its high cooling loads. HDD were calculated according to the standard Swiss definition[6], using a base of 20°C with a cut-off temperature of 12°C. CCD were calculated to the ASHRAE definition[7], using a base of 18.3°C with no cut-off. Heating and cooling degree days for warming climate conditions (“$HDD_{\_warmer\_climate}$” and “$CDD_{\_warmer\_climate}$”) were calculated with the following simplified assumptions for all locations:

1. temperature increase of +1 °C in the months from September to May
2. temperature increase of +2 °C in the months from June to August.

The relative variations of heating degree days are highest for warm climates and the variations of cooling degree days are largest for cold climate zones (Table 4, first part)

Specific final energy demand per m^2 of heated area “$H_{\_location}$” for room heating and for preparation of sanitary water and process heat in these 9 locations was determined by the very rough approximation shown as formula (1), where $H_{\_CH}$ and $HDD_{\_CH}$ are the specific energy demand in Switzerland[8] of 153 kWh/m^2.a and the mean heating degree days in Switzerland of 3514 degree days and the parameter “$a_{\_CH}$ ” is the fraction of heat demand in Switzerland that varies proportionally to the number of heating degree days, approximated by the fraction of total heat demand which is not used for sanitary water and process heat. The specific heat demand for sanitary water and process heat is supposed to be equal to 16 kWh/m^2.a - independent of climatic conditions.

$$H_{\_location} = H_{\_CH} + H_{\_CH} * a_{\_CH} * (HDD_{\_location} / HDD_{\_CH} - 1) \qquad (1)$$

The heat demand in the case of higher mean temperatures is calculated analogously by formula (1).

Electricity demand for cooling per unit of cooled floor area (m_c^2) in the different locations was either taken from Adnot et al. (2003) or calculated with formula (2) determined by a linear fit to Adnot’s simulation results for locations in temperate and Mediterranean cities (Figure 2).

$$El_{\_location} = 12.74815171 + 0.102921 * CDD_{\_location} \text{ , in kWh/ } m_c^2\text{.a} \qquad (2)$$

The calculated specific energy demand for heating (including preparation of sanitary warm water and process heat) and cooling of commercial buildings in the 9 locations and the relative variations in the case that temperatures increase vary considerably (Table 4, second part).

In order to determine the total variation of electricity for cooling we have to evaluate the increase of cooled floor area due to climate change. We assume that in 2030 100% of the floor area is using heat (heating and/or sanitary water and process heat), but that with no climate change only a fraction is cooled. With increasing temperature this fraction of cooled floor area is increasing and the variation of electricity demand for cooling shown in the second part of Table 4 is also increasing. The fraction of cooled floor area (partially cooled is taken as half the area is cooled) in Zurich is assumed to be the same as in Switzerland altogether (section 3): 40% in the case of no climate change and 59% if the temperature increases by 2 °C in summer. These fractions for the other locations are rough guesses (Table 4, third part). The specific energy demand for cooling per unit of total floor area (m^2) of the commercial sector (and not just per unit of cooled floor area, m_c^2) is of course lower – except for Florida, where we assume that all the floor area is cooled) - and the relative increase of electricity for cooling is higher due to the increase of cooled floor area (Table 4, third part).

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[5] Meteonorm is a global climatological database, containing data from 7,400 weather stations around the world. It includes a synthetic weather generator that can generate hourly time series corresponding to "typical years" from monthly values of all parameters using a stochastic model. (www.meteotest.ch)

[6] SIA Standard 381/3: Heating degree-days in Switzerland, Swiss Association of Engineers and Architects (in German), Zurich, Switzerland, 1982.

[7] ASHRAE Fundamentals Handbook 2001 (SI Edition). Chapter 31: Energy estimating and modeling methods, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 2001.

[8] Mean value in 2005 of all buildings in the commercial/building sector.

Table 4 Heating and cooling degree days for today's weather conditions (HDD$_{_mean}$ and CDD$_{_mean}$) **and in the case of a climate change with mean temperature increase of +2 °C in summer and +1 °C in winter** (HDD$_{_warmer_climate}$ and CDD$_{_warmer_climate}$)**; and specific heating** (H$_{_mean}$) **and cooling** (El$_{_mean}$) **energy demand per unit of heated** (m_h^2) **and cooled** (m_c^2) **floor area (2005[9]) for today's weather conditions and variations for increasing temperatures; fraction of cooled floor area in 2030 without** (%cooled$_{_mean}$) **and with** (%cooled$_{_climate_warmer}$) **temperature increase and specific heating** (H$_{_mean}$) **and cooling** (El$_{_mean}$) **energy demand per unit of total floor area** (m^2) **for today's weather conditions and variations for increasing temperatures.**

	Florida	Athens	Murcia	Milan	London	Berlin	Zurich	Copen-hagen	Stock-holm
HDD$_{_mean}$	28	696	1035	2797	2904	3436	3571	3847	4406
HDD$_{_climate_warmer}$	10	502	797	2526	2561	3126	3200	3459	4036
Variation	-64%	-28%	-23%	-10%	-12%	-9%	-10%	-10%	-8%
CDD$_{_mean}$	2219	1061	766	319	63	119	88	26	52
CDD$_{_climate_warmer}$	2644	1337	1021	504	147	229	190	81	122
Variation	19%	26%	33%	58%	133%	92%	115%	212%	135%
H$_{_mean}$, kWh/m_h^2.a	17	43	56	125	129	150	155	166	187
Variation	-4%	-18%	-16%	-8%	-10%	-8%	-9%	-9%	-8%
El$_{_mean}$, kWh/m_c^2.a	241	122	90	50	20	25	22	15	18
Variation	18%	23%	29%	38%	43%	45%	48%	37%	40%
%cooled$_{_mean}$	100%	90%	80%	60%	40%	40%	40%	40%	40%
%cooled$_{_climate_warmer}$	100%	95%	90%	75%	59%	59%	59%	59%	59%
H$_{_mean}$, kWh/m^2.a	17	43	56	125	129	150	155	166	187
Variation	-4%	-18%	-16%	-8%	-10%	-8%	-9%	-9%	-8%
El$_{_mean}$, kWh/m^2.a	241	110	72	30	8	10	9	6	7
Variation	18%	30%	45%	73%	109%	112%	116%	100%	104%

Source: Degree days calculated from data obtained from Meteonorm; other data from CEPE

In order to make a realistic balance of decreasing CO_2 emissions for heating purposes and increasing CO_2 emissions for cooling we would not only need detailed information about the CO_2 content of heating energy and of the electricity used for cooling in the year 2030, but also about the CO_2 content of the avoided heating energy and of the additional electricity used for cooling due to higher temperatures. This will be done by CEPE in a coming research project. Here, we do a simple sensitivity analysis in order to get a feeling about the possible variation due to different fuel choices. In order not to confuse the reader, we do not use any geographic names, but characterise the different locations by their CDD only.

The fuel mix for heating is characterised:

1. by the fraction of electricity in the total final energy demand for heating ("**little**" = 10%; "**much**" = 50%) and

[9] Using today's values for evaluations in 2030 is acceptable for our purpose to investigate relative variations in CO_2 emissions, as long as energy efficiency is improving at a similar pace in the heating and in the electricity domain.

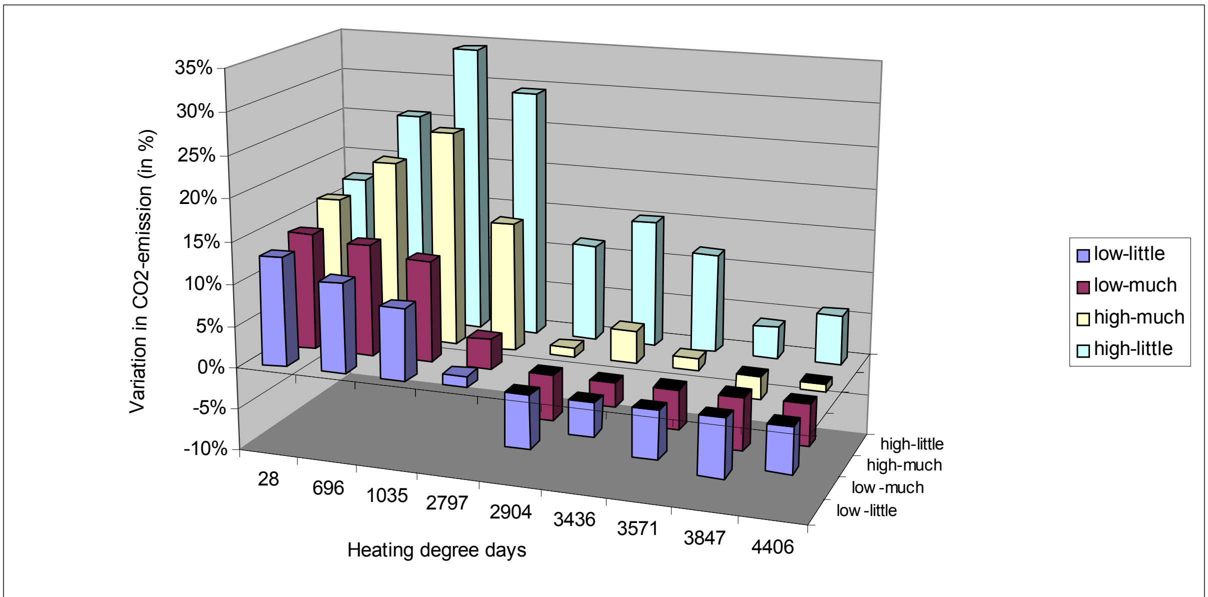
2. by the CO_2 content of the remaining (non-electric) fuel mix used for heating (0.2 Mt CO_2 per TWh corresponding approximately to the CO_2 content of natural gas; 0.3 Mt CO_2 per TWh corresponding to CO_2 content slightly above the one for light fuel oil)

For the CO_2 content of electricity we use the two extremes:

1. **high** CO_2 content (1 Mt CO_2 per TWh corresponding to electricity produced by coal fired power plants)
2. **low** CO_2 content (0.1 Mt CO_2 per TWh corresponding to electricity produced 90% CO_2 free)

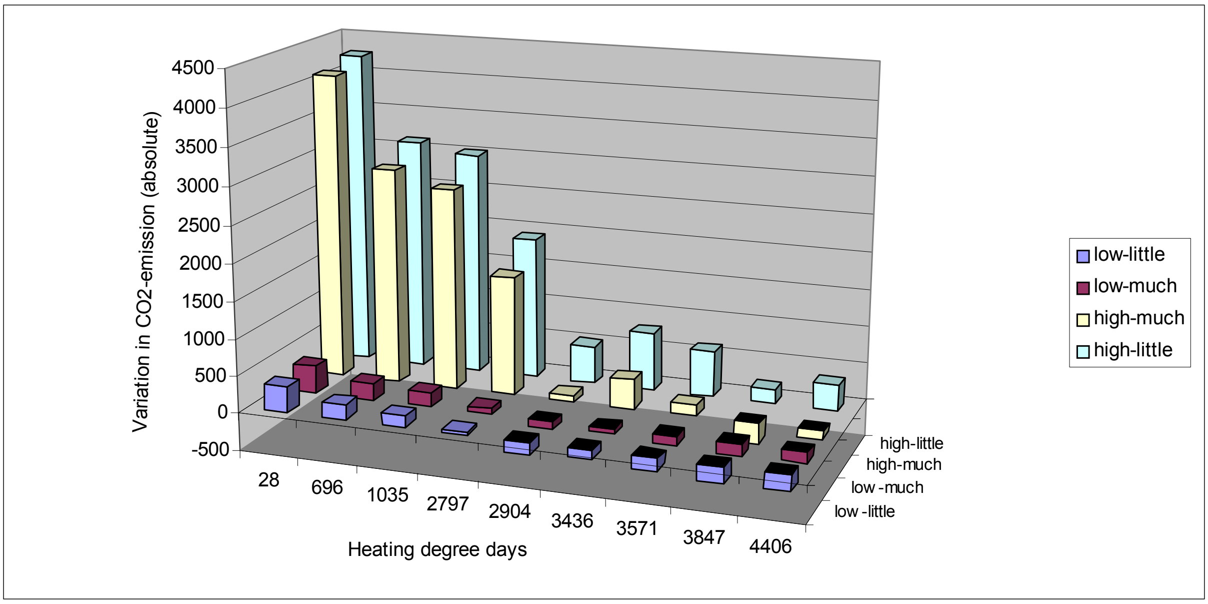
The main outcomes can be summarized as follows (Figures 5 and 6):

- The results depend only weakly on the CO_2 content of the non-electric fuels for heating. We present the results of the fuel mix with 0.2 Mt CO_2 per TWh corresponding approximately to the CO_2 content of natural gas.
- In warm climates, there is a large increase in terms of relative CO_2 emissions in the case **low** and very large increase in the case **high**. The fraction of electricity used for heating has a significant effect, except for the warmest locations. In absolute terms the increase is, not surprisingly, much higher in the case of **high**.
- In cold climates, the variations are in relative and in absolute terms significantly lower than in warm climates. Except in the case of high and **little**, the CO_2 emissions are always reduced by a temperature increase. The fraction of electricity used for heating has a significant influence in the case of **high**.
- In temperate climates, the situation is qualitatively very similar to the situation in cold climates, except in the case **high** and **much**, where the reduction of CO_2 emissions in the cold climate is changed into an increase of CO_2 emissions. In particular, there is:
    - a substantial reduction of CO_2 emissions in the case **low** almost independent of the fraction of electric heating;
    - a substantial (slight) increase of CO_2 emissions in the case **little** (**much**) and **high**
- The large differences between the locations HDD=2797 and HDD=2904 with rather similar heating degree days is due to the large differences in the cooling degree days.



Source: CEPE

Figure 5. Changes in relative CO_2 emission from heating and cooling due to climate change in different locations (characterised by HDD), in percent



Source: CEPE

Figure 6. Changes in absolute CO_2 emission from heating and cooling due to climate change in different locations (characterised by HDD), in arbitrary units

5. Discussion and conclusions

Detailed studies of long term temperature records show that temperatures in Switzerland rose by around 1.3 K during the 20th century, approximately twice as fast as mean global temperature, with most of the increase occurring in the last three decades. The trend towards higher temperatures is expected to continue, and may be expected to lead to a reduction in the need for heating in winter and increased need for cooling in summer. In this paper we explore the impact of a temperature increase of 1K in winter and 2K in summer on energy demand for heating and cooling and the induced CO_2 emissions. A change of this magnitude reduces HDD by about 10% for most locations in Europe. For CDD, the change is much more dramatic in relative terms, in many cases leading to more than double the present levels.

The reduction in HDD and the increase in CDD will tend to have opposing effects on energy use and CO_2 emissions. Increases in CCD are likely both to cause an increase in both energy use in buildings that already have cooling and in the fraction of total floor area that has mechanical cooling. Even a relatively modest increase in summer temperature may therefore lead to a doubling of cooling energy requirements compared to what would be needed if there is no temperature increase.

The net effect on energy use and CO_2 emissions depends on the balance between the effects on heating and cooling needs. For Switzerland, heating accounts for vastly greater energy use and CO_2 emissions than does cooling, as it does throughout North West Europe. Consequently, the effect of large percentage increases in cooling demand can be outweighed by much smaller percentage changes in heating demand. Another important factor affecting this balance is the relative CO_2 intensity of the electricity and heating fuels supplied to buildings. We found, therefore, a very large increase in CO_2 emissions where both summer temperatures and the CO_2 intensity of electricity are high.

Policy measures to reduce cooling energy demand may be aimed both at reducing the number of installations and at reducing energy use in buildings that have cooling capacity installed. The former is arguably the more effective in countries with cooler summers, and is most applicable for new buildings and major refurbishments, where intervention is possible at the design stage. Minimisation of summer cooling requirements is already encouraged by building regulations in some countries, including Switzerland and the UK. Our results suggest, however, that for Switzerland the present focus on avoiding mechanical cooling may need to be supplemented by emphasis on the design and effective operation of cooling systems. The avoidance strategy will remain viable, however, for the northerly maritime areas (including Ireland, the UK and Scandinavia).

Improvements to the efficiency of air conditioning equipment have been the subject of two EU SAVE projects – EERAC and EECAC – which have provided a basis for further intervention, including labelling and minimum efficiency standards. Legislation arising from Article 9 of the Energy Performance of Buildings Directive, which will to come into force in EU countries in 2006, is expected to lead to better maintenance and more appropriate installations of air conditioning equipment in future.

Rising peak demand in summer is an area of particular concern for policy makers. In Switzerland and other countries with moderate summer temperatures, this will not be significant unless the use of air conditioning increases by a very large factor. In the Mediterranean countries, however, it is a problem that needs immediate consideration both for generation and distribution capacity. The EERAC study found that, in countries with summer peaking, additional investment in generation, transmission and distribution may be needed as a result of growing air conditioning loads. The difficulties experienced in recent years in meeting peak loads in California are of interest and may offer lessons for Europe. Wilson et al, 2002, gave estimates of the contribution of air conditioning to the peak demand experienced in 2002. Commercial sector air conditioning was estimated to account for 15% (7000 MW) of the total peak load, with residential air conditioning contribution a further 14%.

In all European countries, it is clear that the design of buildings should no longer be based on past climatic data but should instead take account of expected changes during the planned life of the building. Frank (2005) shows how energy simulation can be used to assess impacts on particular building types and the benefits of particular technical measures, such as night ventilation. More use of building energy simulation should be made for individual buildings in order to take best advantage of opportunities for minimising cooling load through design features.

While becoming more conscious of the need to avoid (where possible) and minimise cooling demand, it is important that policy makers do not lose sight of the continuing need to reduce heating demand, especially in Northern Europe. Even for Southern Europe, where awareness of cooling demand is already strong, heating demand is likely to remain significant and should not be forgotten, especially if it is met by electricity to a significant extent.

Energy statistics in many European countries fail to distinguish energy used for cooling. While this may have been justified in the past by the relative insignificance of cooling in terms of total energy delivered, it is no longer the case. Bodies responsible for the collection of energy statistics should be encouraged to develop methods for collecting and presenting the relevant data.

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Adaptation of Commercial Buildings to Hotter Summer Climate in Europe

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Abstract
Due to global warming, annual temperatures and temperature peaks are expected to rise steadily during the 21st century especially in summer time. The European moderate climate with distinguished winter peaks for heating loads could change gradually to more important peaks for cooling loads in summer. Estimates show that both the summer temperature rise will probably be higher than the average annual rise and urban areas will have higher rises due to higher absorption during the day and reduced natural cooling at night. Existing and new urban commercial buildings with no extra measures will have to deal with a severe reduction in summer thermal comfort that can lead to more frequent and more severe violations of standard requirements for thermal comfort in working conditions.

The so far exceptional 2003 summer showed how longer periods of high temperatures during the peak hours of the day as well as higher temperatures at night have a severe impact on commercial buildings with and without air conditioning systems. In moderate climate in highly industrialized central and northern European the fraction of fully air conditioned commercial buildings in the building stock is still below 30%, with higher numbers for new and large buildings under construction. However, national building energy standards still refer mostly to winter heating conditions. The present tendency in existing buildings is for the users to rapidly install small-scale room air conditioners with low energy efficiency ratios. This is of course no remedy for a severe development that has to be solved systematically for buildings with a life cycle of 30 to 50 years.

The rise in summer electricity demand depending on higher outdoor temperatures is already visible in moderate Swiss climate and reflected in European summer electricity price peaks. To prevent this rise to continue two major areas of building activities have to be improved: First existing buildings will need retrofit packages with better sun protection (hardware systems including managing strategies), reduction of internal loads due to lighting and appliances, more energy efficient room air conditioners and (solar) efficient cooling systems. Second design standards for new buildings will have to cope with not only average historic design reference years but with unusually future higher temperature conditions. This must lead to a combination of more stringent design standards for sun protection systems, lower internal loads from office equipment and lighting, better allocation of thermal mass and requirements for more energy efficient ventilation and cooling systems. Recent studies show that these standards can be met with low additional life cycles costs and that they would create additional benefits, e.g. through increased thermal comfort.

1 Background

Summer electricity peak in Europe

The usual peak load in the European UCTE electricity grid is observed in winter (440 GWe) with cold external temperatures and an additional load due to resistance heating and other thermal processes. This is also typical on a national basis for the mid- and northern countries. It is not so for the southern countries like Italy or Greece, where the summer load is at the peak when external temperatures are high and additional cooling loads become dominant. Many countries with moderate climates are moving their annual load profile slowly from the dromedar type with one (winter-) peak to the camel type with a winter- plus a summer peak because of increased cooling loads in new commercial buildings. In this paper we are dealing with rising summer temperatures and their impact on technical solutions and energy demand in buildings.

In Switzerland the relative change of monthly electricity demand for the hot summer of 2003 is shown in Figure 1 where the three two summer months July and June top the other months.

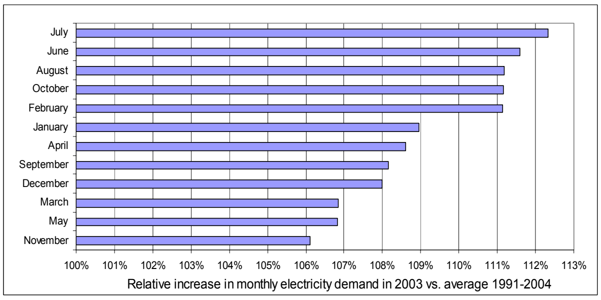


Figure 1 Switzerland monthly increase in electricity demand in the hot summer year 2003 compared to average of 1991 - 2004
[1] Swiss electricity statistics 2004

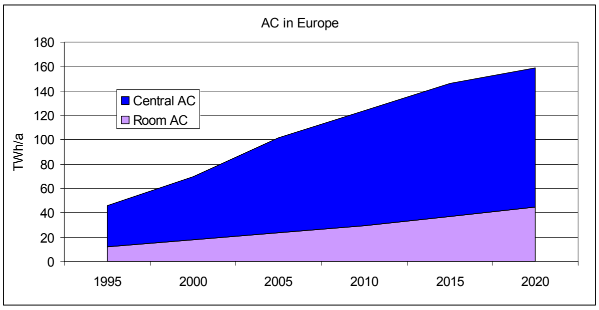
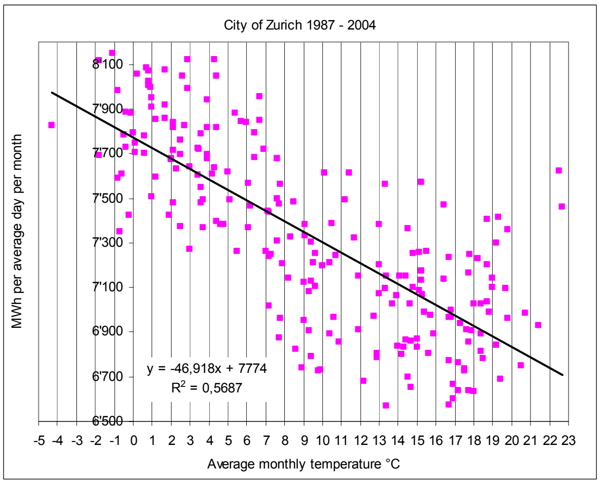


Figure 2 Europe (15 countries): Electricity demand for air conditioning [4]

Electricity demand and external temperature

In the city of Zurich the development of monthly electricity demand was analyzed with external temperature data from 1987 to 2004 as the major effect. The typical regression for daily demand versus average monthly temperature is shown below: On the left side (figure 3) the regression for all data shows some 2.5 GWh per month additional demand when the monthly temperature is 1 K lower. On the right side (figure 4) the summer months above 17°C average monthly temperatures change the slope and deliver an additional demand of 11 GWh per month and K. Both tendencies are below a lot of "noise" stemming from the general increase in demand and other summer/winter factors that are not necessarily dependent on exterior temperatures (holiday and outdoor period, etc.).



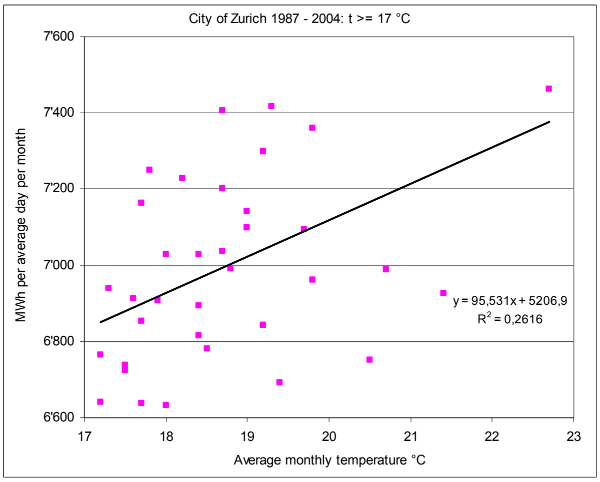


Figure 3, 4 Switzerland monthly increase in electricity demand in the hot summer year [2], [3]

Cooling load neglected

In winter and heating oriented northern countries the summer loads were often neglected. Either the winter peak loads for space heating and ventilation were actually dominant for building and equipment design, or the tolerances for thermal comfort in summer peak temperatures were larger, i.e. no need was seen for installing air conditioning for rare occasions of uncomfortable room conditions. The situation has changed out of many reasons:

- The accepted level of tolerance in thermal comfort in work places today is lower because the prolonged computer-oriented fixed sitting position does not allow for change of body position.
- The average floor area in square meters per user in modern offices is smaller.
- The number of new commercial building "vulnerable" to high indoor temperatures due to higher percentage of exterior glazing and lower internal mass has increased.
- The thermal base load due to electronic office equipment and lighting has increased.
- The external summer temperatures have notably risen in the last two decades especially in inner cities where commercial buildings are located.
- New cars come more frequently equipped with air conditioners. This changes the general expectation for indoor climate.

Projections for central and room air conditioning in Europe from IEA [4] from 1999 and 2003 show that the electricity demand will accelerate both from new market penetration of equipment and warmer summer climate between 2005 and 2020: The cooled floor area will go from 2'100 to 3'300 billion square meter, the electricity demand from 102 to 159 TWh/a.

In Switzerland there is a general aversion towards room air conditioning: The general sentiment is that it is not needed in our climate and should therefore not be standard equipment. It will cause additional investment, higher running costs for energy and maintenance. And it is doubtful that higher user satisfaction can be achieved after all. Some cantons have adopted restrictions or bans on building permits for new air conditioning systems. At last a higher threshold (room simulations, low internal load, excellent solar shading, etc.) have to be proven to be eligible for an ac permit.

In [5] we showed that even in highly glazed buildings the thermal comfort can be maintained and electricity demand can be low if adequate measures are taken. These measures include low internal loads (persons, appliances) including efficient lighting with daylight and occupation sensors and controls, ventilation including night cooling, excellent solar shading and thermal insulation. In terms of electricity demand, highly glazed buildings perform better even if active cooling is applied (cooling of supply air and limited additional cooling).

Consequences for the electricity demand

The consequences of a warmer climate on the electricity demand depend on three main factors

- Amount of additional floor area with cooling induced by the warmer climate
- Share of technologies (room AC, central AC, type of refrigeration)
- Quality with respect to energy-efficiency of technologies, planning and operation

Following the experience of summer 2003 it can be expected that cooled floor area would be extended considerable and that this extension will be realized to a non-negligible extent by portable small-size air-conditioning appliances. Since the installation and use of these systems is not covered by direct legal standards and since most of the existing small-size systems have very low efficiencies with COP <2 an increased electricity demand and new peaks for electricity power in summertime in uninfluenced development has to be expected.

Existing building codes and standards

Today's building standards exist in three major categories: One for calculating, optimization and requirements for annual building energy demand (EU: EN ISO 13790 and prEN 15'203; Switzerland: SIA 380/1 and SIA 380/4), another group for dimensioning, optimization and requirements of heating, ventilation and cooling equipment (EU: EN 13'779, prEN 15'241, prEN 14'335 and prEN 15'243; Switzerland SIA 382 and SIA 384) and a third standard for thermal comfort (EU: EN 13779, CR 1752, prEN 15'251; Switzerland SIA 180). In all these standards the predominant concern is the calculation procedure; in the case of the SIA Standards for winter heating, maximum heat load, and thermal comfort in winter precise minimum requirements are given. The thermal comfort conditions are included for summer conditions in SIA 180, but the application shows problems with its practicability. Only in the new SIA 382/1 (2006) a requirement for the COP of room air conditioning systems appears. In the new SIA 380/4 (2006) for the first time a calculation module for ventilation and cooling will be included. The existing design tools for calculating maximum cooling and heating loads (Design reference year DRY 1984) are still based on historical external temperature series (1960-1990). The slow change over the last decades has not yet been incorporated in these data files.

A series of not manageable buildings under summer conditions have increased the pressure on investors and planners to start designing better-adapted buildings for summer conditions.

The typical design life cycle for buildings is 30 to 50 years, for their HVAC equipment 20 years. Major building design features therefore have to be based on an appreciation of the future climate over the next 5 decades, secondary equipment design features on 2 to 3 decades.

The summer of 2003 as a preview

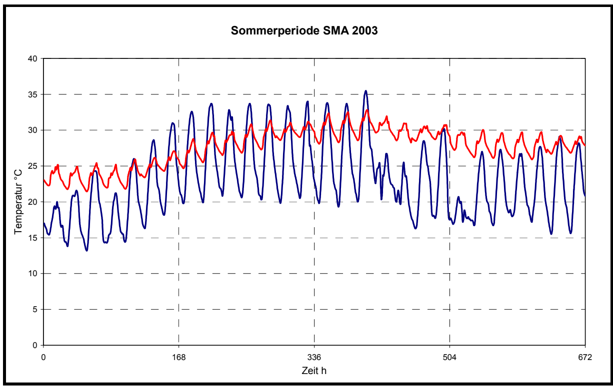
The experience of the exceptionally hot summer of 2003 has sparked both the user's and investor's concern and stimulated the engineer's and architect's renewed interest in better building dimensioning tools. Only now a group of scientist is planning on a DRY hot that would include experiences from the year 2003.

In the year 2003 the average temperature was in Zurich/Switzerland (representative for the major part of commercial buildings in the country) 1.8 K higher than the "old" long-term-average given in SIA 380/1 and 0.7 K higher than in the period 1987-2004. Looking at the summer peak situation, the differences are even higher (see table 1).

Table 1: Average and 2003 summer temperatures in Zurich SMA

Climate Zurich SMA	peak year	average		deviation	
° C	2003	avg. SIA 380/1	avg. 1987-04	2003 - avg.SIA	2003 - avg. 1987-04
Year	**10,23**	**8,45**	**9,52**	**1,78**	**0,71**
Summer 6 months	17,28	14,13	14,95	3,15	2,33
Summer peak 3 months	21,67	16,57	17,81	5,10	3,86
June	22,50	15,80	16,37	6,70	6,13
July	19,80	17,50	18,40	2,30	1,40
August	22,70	16,40	18,65	6,30	4,05

The figures below show the result of the simulation in [6]: The summer 2003 hot days (> 30°C daily peak) in Zurich SMA numbered 12 (figure 6), instead of the average 5 (figure 5). The peak four weeks summer period had an average temperature of 23.0°C instead of the usual 18.6°C. The internal temperature response reached more than 21 days instead of the usual 1 day above the critical limit of 28 °C.



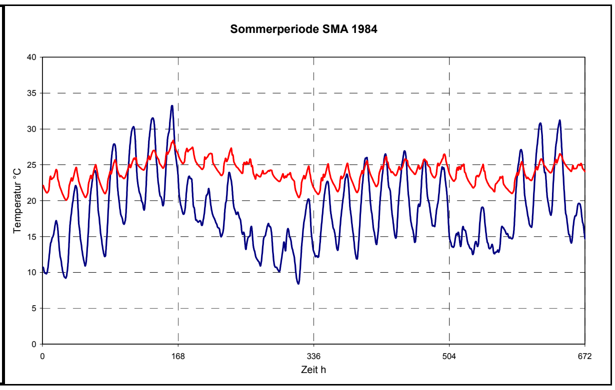


Figure 5, 6 Zurich SMA Summer conditions: External temperatures and temperature response in a 20 m2 reference office room [6] Red: internal, blue external temperatures. Figure 5: year 2003 (4 weeks July/August), figure 6: design reference year (1984)

2 Future climate scenario

State of incertitude
A number of up to date research papers have been presented recently to quantify the expected temperature change in Switzerland over the next century. The general assumption is for a more volatile climate with larger and longer deviations from average for precipitation, wind, temperature, humidity etc. The results from the papers for the average temperature rise are in a small band of deviation. They are distinguished by length of period, by national or micro topology (50 km grid) and by additional climate features (precipitation, radiation, air humidity, wind speeds, hydrology etc.) discussed. A general agreement seems to be on the order of magnitude of + 2 to 3 K until 2050 compared with the average of 1960 to 1990. The Hydram [7] paper that allows for two different scenarios (A: medium-heavy emissions; B: medium-low emissions) and a 50 km grid shows the following results (figure 7). For the northern cities of Zurich, Winterthur and Basel the temperature rise until 2099 will be from 5 to 7 K, for the central and western cities Bern, Geneva and Lausanne between 5 and 7.5 K. For the more central location of Lucerne it will be between 4.5 and 6.5 K. The variations between the regions inside Switzerland are not large and less scientifically secured. The development of this temperature rise will be exponential, that means in mid-period not yet half the temperature rise will be evident.

Bases for calculation
In order to have a chance to assess the impact of additional cooling energy demand over the next 5 decades a baseline scenario for the climate evolution has to be established. For building purposes temperature, radiation and humidity are most relevant.

We base our main calculations for 2050 (relative to the 1960-1990 averages used so far) in Switzerland on:
- Average 3 K summer temperature rise in densely populated areas (all cities about equal).
- Slightly higher rise of night vs. day temperature (lower daily amplitude of temperature change).
- Average global radiation unchanged.
- Average relative humidity unchanged (i.e. absolute humidity will increase accordingly).
- Winter: not considered in this paper.

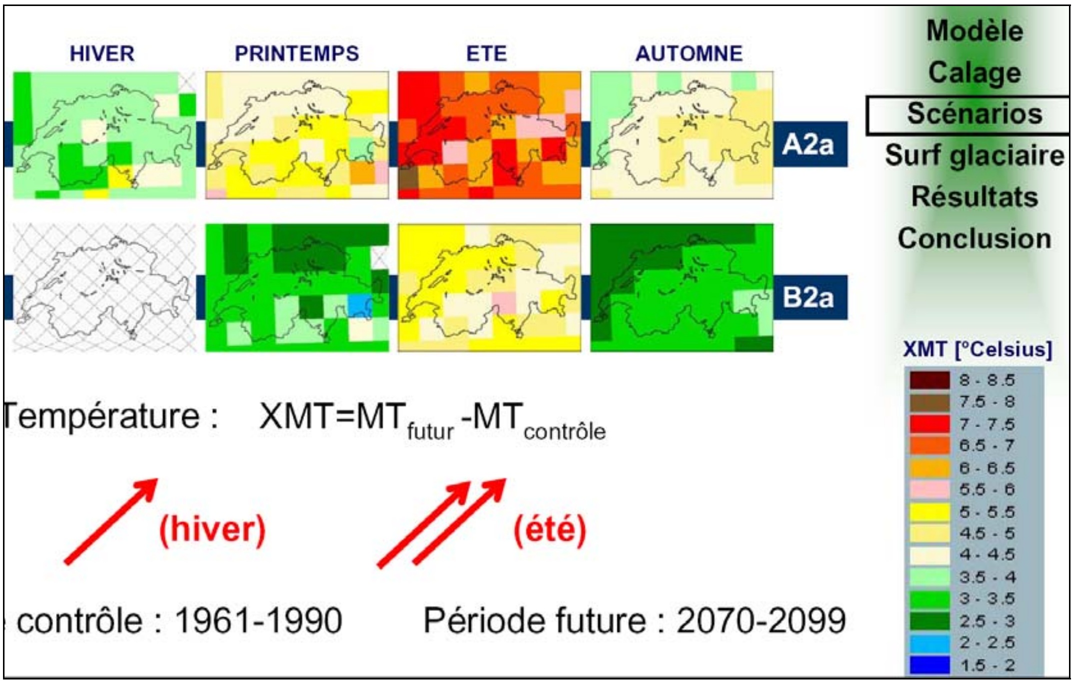


Figure 7 **Switzerland temperature change projections for 2070 to 2099 in scenarios [7]**
A2 medium heavy green house gas emissions, B2 medium light green house gas

3 Major energy-relevant impacts and measures

Impact to the building

Protection against solar radiation and high outdoor temperatures

The protection of buildings against cold weather has a long tradition in our climate. We are nowadays used to apply thermal insulation with a thickness of 0.20 m and glazing with U-values below 1.0 W/m^2.K. On the other hand the protection against solar radiation and high temperatures in summertime has not made yet great progress.

With hotter summer climates the relevance of protection-measures against external thermal loads is clearly higher. In fact, average global radiation is assumed to be unchanged (see above), but thermal load of air exchange is increased and probability of periods with consecutive warm days is increased. In addition we have to face a trend to more a dense building occupation (less square meters per person) and to an architectural trend of facades with higher percentage of glass.

Based on existing climate situations and energy efficiency experience the Swiss standard SIA 382/1 has a new requirement to the g-value of windows including sun protection. This ensures that the resulting external load per m^2 of facade is not any more depending on its orientation and percentage of glass area. With hotter climates such requirements are becoming more and more important. In addition the protection system must be flexible to changing needs during the day and the season. And it must allow a good use of daylight combined with an effective sun protection.

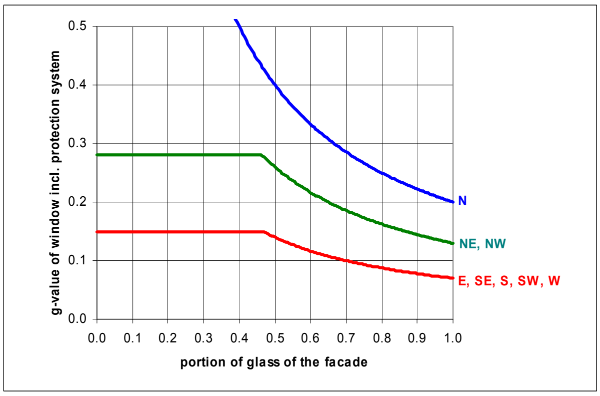


Figure 8 Requirements to sun-protection system in the Swiss Standard SIA 382/1 [8]

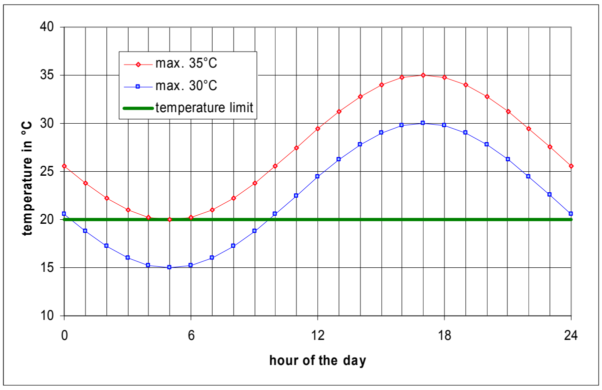


Figure 9 Profiles of outside temperature and limit for natural cooling (20°C)

When looking at the thermal fluxes with hotter climates one realizes, that a good thermal insulation reduces the fluxes in both directions. This means, that the good thermal insulation we use for the protection in winter time helps to reduce the external loads in situations with the outside temperature above the room temperature but reduces also the natural cooling during night time.

Thermal mass

It is commonly accepted that a building with high thermal mass has advantages with regard to the need of cooling, the cooling capacity when cooling is needed and to the thermal comfort in general. However, the mass can only play its role, when there is a temperature difference which means no constant room temperature. With a HVAC-system running for a constant room temperature, the thermal mass plays a minor role with respect to the power and energy needed. But it is helpful for situations with no cooling and for cooling with limited capacity. With a hotter climate with more consecutive warm days the above mentioned advantages of high thermal mass will decrease.

Reduction of internal loads

The cooling load of a building is the result of external and internal loads. High internal loads cause not only a high electricity demand for the equipment itself but also an additional energy demand for the cooling. Alternatively we have to accept lower thermal comfort due to higher room temperatures. In a warmer climate, the need for reducing internal loads is even more relevant.

First results on quantitative estimates

To estimate the impact of warmer temperatures as described above building simulations were made for about a dozen of cases of new buildings. These cases cover a wide range of potential factors that influence the cooling energy demand of buildings. In particular, the following parameters were varied: internal load of persons and appliances, installed lighting load and lighting control concept, share of glazed building envelope, glazing quality, quality of sun protection and control concept, indoor temperature requirement, etc. Each case was run with a today's climate data set (for Zurich, Switzerland) and with data set of increased temperature (+2.5 K during the day and +3.5 K during the night. In figure 10 and figure 11, first results of these simulations are given. Note that annual COP has been remained constant and thus, these results represent the impact on the building only (excluding the impact on the HVAC system).

According to these result the increase of electricity for cooling due to warmer climate is between 10 and 30 MJ/m²a (figure 10). The relative increase is between 20% and 50% for buildings with typical cooling energy demand (40 to some 100 MJ/m2a). For buildings with low cooling demand (that include free cooling through windows, for instance), the relative change may be up to 200% (figure 11). If compared with the total electricity demand of buildings, the impact of warmer climate varies mostly in a range 5% and 10% and reaches 15% in one case.

Note that the impact of warmer climate in terms of cooling energy demand (in absolute values) is much smaller than the differences between the cases considered. This means that even with warmer climate, the cooling energy demand can be reduced substantially, in particular below the demand of many cases with today's climate.

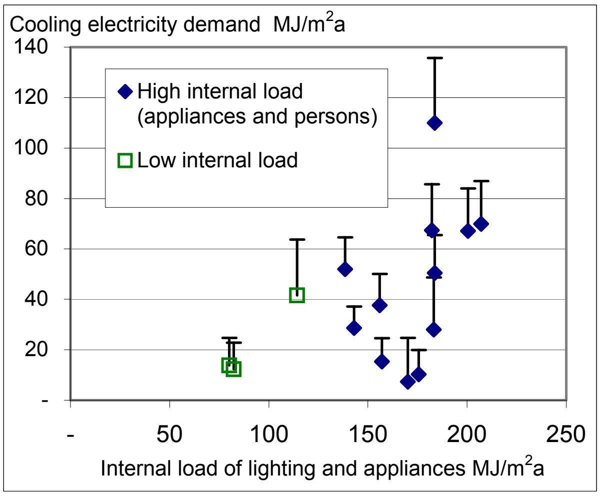


Figure 10 Sensitivity of cooling electricity demand regarding warmer outdoor temperatures (absolute values)

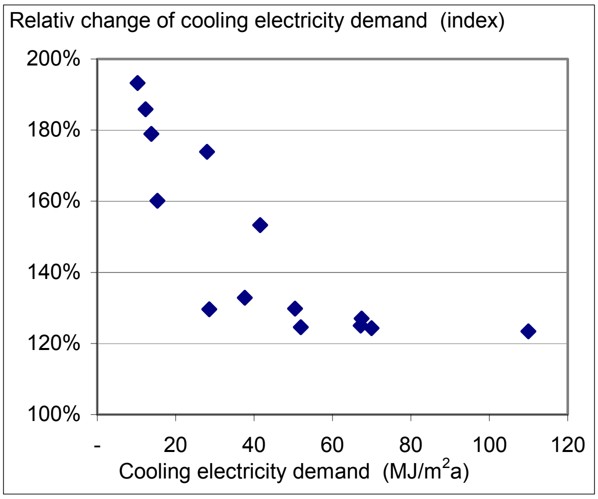


Figure 11 Sensitivity of cooling electricity demand regarding warmer outdoor temperatures (relative change, 100%=demand with today's climate)

Impact to the HVAC-system

Limits for natural ventilation and systems with no cooling

In situations with natural ventilation or with systems without cooling the supplied air has more or less the same temperature as the outside. Thus, a warmer climate has two main impacts: First, during periods, when indoor temperature is lower than outdoor temperature, thermal load is increased because of higher outdoor air temperature and because ventilation cannot be reduced below a certain minimum. Second, during periods when indoor temperature is higher than outdoor temperature the cooling effectiveness of natural or forced ventilation is reduced (with respect to thermal comfort in warm periods ventilation should be made whenever possible during the night and early morning when the outside temperature is low).

Experiences show, that for an effective natural cooling during the night, the outside temperature should be below 20°C. On a warm day with a maximum temperature of 30°C and an amplitude of 7.5 K (traditional design day) this is the case between midnight and 9 a.m. With higher outside temperatures the time window for an effective natural cooling is smaller. On a warm day with a maximum temperature of 35°C the temperature-minimum is not any more below 20°C (figure 9, see also figure 6) and a natural cooling is not any more effective.

Need for mechanical ventilation and cooling

With a warmer climate we have not only to cope with higher external loads but also with the fact that natural cooling during day and night is less possible. When we do not accept higher room temperatures, we need technical systems which supply fresh air with acceptable temperatures. This would help to control the room temperature in the limits of thermal comfort.

When looking at the existing building stock with a high degree of natural ventilation or simple ventilation systems with no cooling one must expect a relevant shift towards HVAC-systems with cooling.

Energy-effective ventilation and refrigeration

In the summer 2003 there was a run to portable small-size air-conditioning appliances. Several shops were completely sold out. Once installed, these systems will be operated even in situations where it is not really needed. Most of the existing small-size systems have very low efficiencies with COP < 2. To a large extent, these low COP are due to thermodynamic principles and due to their type of construction (compressor is located in the room and therefore heat load is increased due to their waste heat).

Built-in cooling systems also have a risk to run on low overall COP and/or to run unnecessary. However, if adequate measures are taken, annual COP can be increased considerably. The main measures for energy-effective HVAC-systems are

- Short duct system with low air velocities and low pressure drops
- Fans and motors with high efficiency
- Refrigeration/cooling with high annual coefficient of performance
- running of the system adapted to the real needs

Field measurements show very big differences in the energy consumption of HVAC-systems for a comparable thermal comfort. The coefficient of performance COP for different solutions for refrigeration is in a range of 1:3 (see figure 12). More advanced standards are needed to raise minimum energy performance standards for room and central air conditioners.

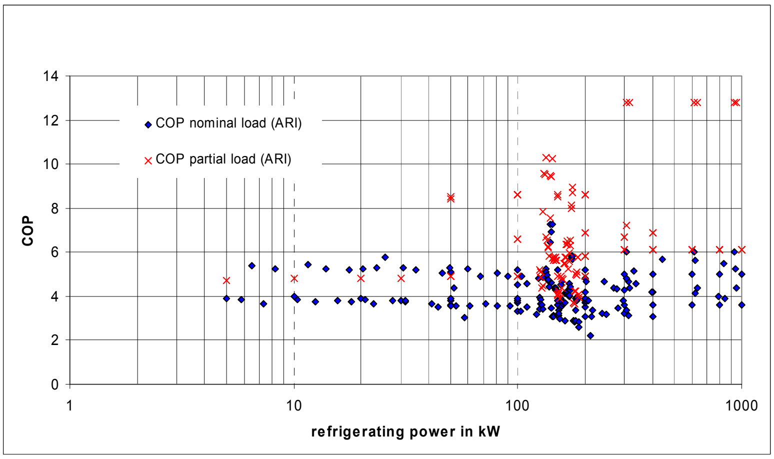


Figure 12 **Coefficient of performance COP for different solutions for refrigeration [9]** (result of market-survey 2005 [9])

4 Cost and benefit analysis of adaptation strategies

With an increasing warmer climate building owners, operators and users will have to face increasing costs, negative impact and/or additional benefits. This is true for both the construction of new buildings and for the operation and renovation of exiting ones. In the first subsection typical data of additional direct costs and benefits are given, in the second subsection the potential negative impact on thermal comfort and its economic valuation is addressed and in the third subsection potentially induced additional benefits.

Additional direct costs and benefits

Gross additional costs due to a warmer climate can be induced because of several reasons. We distinguish between induced costs because of more extreme weather events but low average change (and its consequences to investor's decision) and clearly increased average temperature rise in summer (and its consequences to the energy demand of buildings with installed cooling).

- Warmer climate may influence building the decisions of owners and investors and/or the legal framework making cooling a requirement. Typical costs of ventilation and/or cooling or other measures to satisfy thermal comfort requirements or comfort demands are given in table 2. The investment costs differ substantially between the different systems. The total annual costs (annualized investment costs, operating and maintenance costs (O&M) and energy costs) are much more similar between the different system types. The annual costs of central cooling systems or portable cooling appliances are typically between 10 and 15 CHF/m^2 a, the costs of regulated window systems between 3 and 5 CHF/m^2·a[1]. If ventilation is included, the cost is between 13 and 17 CHF/m^{2}a.

Table 2: **Typical values of specific costs of additional cooling**

	Investment (CHF/m^2)	Capital Costs (*) (CHF/m^{2}a)	Total Costs (**), today's climate (CHF/m^{2}a)
Ventilation including cooling	165	11.1	15.8
Additional central cooling in existing buildings (w/o ventilation)	95	6.4	9.7
Portable cooling appliances (w/o ventilation)	112	7.5	12.3
Regulated window opening system	50	3.4	3.7

(*) Using annuity method with typical techno-economic lifetimes and real interest rate of 3%
(**) Total Costs include capital costs, O&M costs and energy costs (electricity price 0.17 CHF/kWh)

[1] 1 CHF = 0.65 Euro (2005)

- Increased costs because of higher specific cooling demand (peak or average) and because of higher uncertainty: With more extreme weather seasons it will be more difficult and more complex to plan and design cooling systems in a cost-effective way. Designing capacity to extreme cases could lead to high investment cost and rarely used capacity. Designing capacity to past or assumed future average weather conditions could lead to insufficient cooling services in many periods. That is, design and optimization would have to cope much more with uncertainties. Hedging against uncertainties would lead to additional cost. We estimate that investment cost and thus capital costs would increase by 20% to 40% (as compared to the reference scenario). Note: if the temperature rise were uniformly 2 to 3 K, the peak load would increase less, namely by 10% to 20%, as our simulation results show.
- Additional legal codes and standards call for additional measures or for energy-efficiency limits. If warmer climate and/or the more intensive use of building cooling become evident, it can be expected that legal bodies and authorities would adjust their codes and standards. In Switzerland, typically installed load for ventilation and cooling and/or efficiency coefficients like COP, efficiency of motors or ventilators or specific electricity demand for ventilation could be limited. This could temporarily cause additional costs, for instance for larger air conducts, more efficient chillers, more intensive planning etc. However codes and standards are usually designed under consideration of cost effectiveness. In [10] it is shown that for ventilation and cooling, increased energy-efficiency is either economically viable or leads only to low additional costs of some few CHF/m^{2}a. This is much less than the total costs of induced additional cooling (see above, table 2). This is true for today's climate. In a warmer climate the economics of more energy-efficient cooling will even be improved (see below, figure 13)
- Increased electricity demand of existing HVAC-systems or of HVAC-systems which would have been installed also without warmer climate: In today's climate typical energy costs for cooling (without ventilation) are between 1 and 3 CHF/m^{2}a for office buildings (and 3 to 5 CHF/m^2·a for the retail business sector). With a temperature increase of 3 K, energy demand for cooling could by 20 to 50% for conventional cooling concept and up to 100% for cooling concepts that include free cooling. If cooling service is provided with unchanged efficiency, energy costs would increase accordingly, i.e. by 1 and 3 CHF/m^{2}a for office buildings. That means that total costs for cooling services as stated in table 2 would increase by 15% to 30%

So far we only made quite static considerations. However, in a warmer climate with increased energy demand for cooling services there will be a shift in the economics of energy-efficient cooling. More efficient technologies will become economically viable since a similar amount of additional capital costs profits from an increased amount of energy cost savings (compare warmer climate, today's technology with today's climate, today's technology in figure 13). More efficient technologies such as hybrid cooling towers, larger heat exchanger, cooling cycles with low temperature differences (see [11] for a description) which might not pay for itself in today's climate could become economically viable in a climate that is clearly warmer in average (see figure 13 for an exemplarily illustration)

Further, warmer climate, legal standards and the mentioned shift of the economics will induce a more frequent application of the more efficient technologies. This would stimulate techno-economic progress through learning curve effects. Indeed, the economic literature and numerous studies have shown experience curve effects for such different energy technologies as power generation (coal, combined cycle power plants, wind, photovoltaic, co-generation etc.), end-use technologies (heat pumps, co-generation, biomass plants) and energy-efficiency measures (wall insulation and windows), see [12], [13], [14]. It can be expected that experience curve effects also occur for building cooling services. Usually techno-economic progress is larger and faster for more energy-efficient technologies since they are in an earlier stage of market development (as compared to mature and widely applied technologies). The improvement of the economics of the more energy-efficient technologies becomes even more pronounced (compare warmer climate, future technology with warmer climate, today's technology in figure 13, where a cumulative techno-economic progress of 20% and 30% is applied to the standard technologies and to the energy-efficient technology respectively.

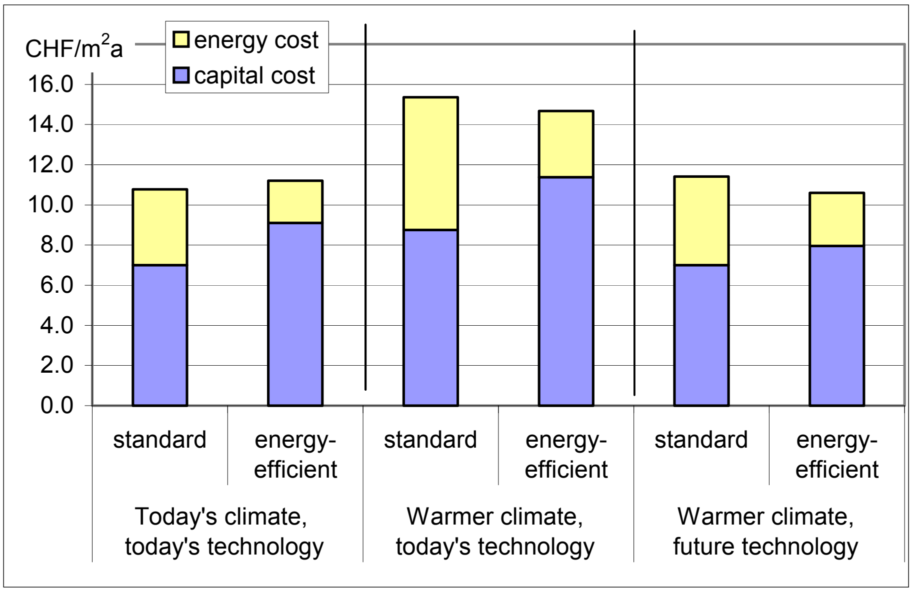


Figure 13 **Typical cost structure of cooling systems for today's climate and warmer climate, including techno-economic progress for future technologies**
(Exemplarily illustration)

Negative impacts on thermal comfort

Without any compensatory measures, levels of thermal comfort would be decreased substantially. This is especially true for buildings with high internal loads, highly glazed facades, insufficient sun protection, and ventilation without cooling, etc. and for rooms oriented east, south and west. Results of building simulations show that the number of thermally uncomfortable hours (temperature greater than requirements of SIA 382/1, but not more than 2°C) increases from some dozens or few hundred hours per year to several hundred hours to more than thousand hours. For some hundred hours, room temperatures increase even to a level of more than 28°C and for some dozens or few hundred hours even to a level of more than 30°C. This means that these rooms are out of comfortable or acceptable conditions for a large proportion of their using periods.

This negative impact could become economically relevant in two ways:

- Labour efficiency of building users is decreased: Several labour-physiological studies (see [15] for an overview) indicate that in the commercial sector, labour productivity decreases substantially if room temperatures exceed 28°C or even 30°C. Typical labour costs in the commercial sector amount to 10'000 to 20'000 CHF/m^{2}a (depending on salaries and occupation density). Gross value added by square meter is even higher. If productivity decreases by 0.2% to 1% (10% to 20% of the time by 1% to 10%) this create additional yearly costs of 20 to 200 CHF/m^2 and revenue loss could even be higher.
- Building rents and building values are decreased: it is commonly accepted and largely underlined by the economic literature and numerous studies that building rents and property values are differentiated according to their attributes (hedonic pricing). Attributes that have a positive impact on building users' utility would have a positive impact on building rents (and thus owners' revenues) and building values and conversely, attributes with disutilities would lead to building depreciation. This means that buildings, which are not hedged against warmer climate, would be depreciated and comfortable buildings would be appreciated. Results from recent studies ([16], [17], and [18]) show that in the residential sector comfort ventilation systems have a positive price impact of 6% to 10%. If there was a similar price differentiation for commercial buildings this would mean a price impact of 20 to 40 CHF/m$^{2\cdot}$a. This value is clearly higher as the costs of installing additional ventilation and cooling (cf. table 2) and as a consequence the economic incentive to add additional cooling devices is not negligible.

Additional benefits

Already in today's climate a non-negligible share of the existing building stock suffers from insufficient or unsatisfying thermal comfort conditions. If additional cooling service technologies are installed due to an induced change of the investors' behaviour (as described above), thermal comfort in summer could be increased substantially. This would create additional benefits in the same order of magnitude as the above mentioned negative impacts. These benefits would exceed by far the additional cost of implementing these services and as a consequence the economic incentive to add additional cooling devices is not negligible.

5 Conclusions and recommendations

The experience of energy-efficiency under present summer conditions shows that by no means the ventilation and cooling systems and the sun protection are in an optimal range for energy-efficiency. With summers in the coming 50 years to be much warmer over longer periods in moderate European climate over the life cycle of new buildings being planned, built and operated a much more comprehensive approach has to be started to improve both summer thermal comfort for users and energy efficiency and to reduce global warming due to substantial additional demand for electricity. We estimate that the additional electricity demand is caused in the first place by an expansion of cooled floor areas and buildings (as compared to additional demand of already cooled buildings). Thus, the laissez-faire tendency (to have users buy cheap room air conditioners with low COP) is certainly no effective program for European climate policy contributions. The EPBD and national standards and building codes have to be upgraded in order to improve energy-efficiency in summer conditions by a large margin. The technology and the design tools are readily available but not yet widely used. Additional cooling and/or ventilation induce additional costs. However energy-efficient ventilation and cooling can be realized economically if life cycle cost principle and warmer climate are applied. Hedging buildings against warmer climate creates benefits that exceed costs clearly.

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Airconditioning Surveys in the UK Retail Sector, or 'Keeping the Cold in'

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Abstract
It is known that airconditioning use in some sectors of the UK's non-domestic building stock, is increasing rapidly and may be approaching saturation, but exact reliable figures are scarce. It is important also to know the reasons for such an increase and if energy efficiency measures are being used effectively to limit the power required by AC (Air-conditioning) units. Systems exist primarily for the comfort of customers and staff, also for stock preservation in the case of food, but the same effect can be achieved with much less energy use, particularly in temperate climates such as in the UK. Typical energy efficiency measures in the retail sector may include more efficient use of display lighting, more and non-arbitrary setting of cooling temperatures combined with self closing doors or air curtains.
The results presented in this paper are from a broad-brush (low data depth, but from a large sample) pilot survey of around 700 retail premises from in 4 UK towns and cities. This was found to be a very effective way of gathering key data for a statistically valid, large sample, in a matter of days, helping surveys to coincide, for example, with favourable weather. Although the surveying process was largely qualitative there was also some quantitative sampling. To assess the intensity of cooling energy use, a sub sample of about 20 retail premises was probed for temperature and relative humidity. The results reported in this paper show that, in some cases, temperatures could be set higher improving thermal comfort and contributing towards a more efficient use of the air conditioning units.
Lessons learnt from the pilot survey and details of a follow-on major survey, numbering thousands of premises, primarily in order to provide longitudinal data, are described. The results gathered so far are cause for concern, and show that despite the increased energy costs involved, very few UK retail outlets adopt any strategy of energy saving for air conditioning use.

1. Introduction

Since the early 1970s the rate of growth in UK energy consumption in the service sector, (i.e. commercial and public buildings), has increased by approximately 30% compared with a 25% increase in the domestic sector [1]. Of the total UK energy consumption of 6,695PJ in 2000, 880PJ was used by the service sector, of which 160PJ or 15% was consumed by the retail sector [2]. Increasing floor space in the service sector has been accompanied by rising energy intensity. In office buildings, demand for air conditioning has grown rapidly alongside a dramatic increase in CO_2 emissions [3]. In the EU as a whole, the growth in AC use by treated floor area has increased by almost 400% since 1980 [4]. For the UK in 2000, total area air conditioned in all buildings, under both cooling and reverse systems, was estimated to have almost doubled (188%) from over the previous decade to 204 Mm² and is projected to nearly double again (196%) by 2020 to more than 400 Mm² [5]. This corresponds to an increase in energy consumption from 8.5PJ in 2000, to almost 16PJ in 2020 and a rise from 826kt to 1540kt in CO_2 emissions. Detailed figures for UK energy consumption by sub-sector or by air conditioning system, are sparse. However by the end of 1994, about 11%, or approximately 10 Mm^2, of retail area was estimated as being air conditioned [6]. By 2000 ventilation and cooling was calculated as accounting for about 8PJ or 5% of annual energy consumption in the retail sector, with rapid growth expected particularly for packaged rather than central air conditioning systems [5;6].

The UK has a temperate climate without large seasonal extremes of temperature, summers are cool and winters are mild. However, eight out of the ten warmest years recorded in England happened in the last 16 years. AC usage in the UK's retail sector is a relatively recent phenomenon but as the global climate is climate warming, the sudden growth of AC usage is something to be concerned about.

The low depth survey was carried out because it is believed that a statistically large number of premises, can provide an indicator to the growth of AC use in the UK within the retail sector. Of additional interest, are the longitudinal possibilities of such a survey, whereby once most of the database is populated the same sites can be re visited in the next years, and the growth of AC use examined year on year. So in addition to examining this growth, the energy efficiency measures applied were also assessed.

Typical energy efficiency measures may include air curtains, traditionally used in the UK to isolate a heated area from the outside in winter, but increasingly finding application in commercial refrigeration [7]. Self-closing, or automatically closing doors may also be useful in keeping the cooled air from venting to the outside. There has been some previous work in the areas of AC and retail, particularly with a view to reducing energy consumption. A survey of 4 shopping centres in Hong Kong, [8], found that air conditioning and electric lighting were the major electricity end uses, accounting for around 85% of the total building energy use. Work in Turkey [9] aimed to reduce energy consumption by defining new HVAC control strategies and tuning control loops in a shopping centre. New strategies were implemented with the help of the existing building management system (BMS) and about 22% energy saving was achieved.

2. Methodology

2.1. Low depth surveys

Surveys were carried out in many cases by examination of installed airconditioning and energy efficiency measures from outside. When airconditioning use was unclear, the survey was extended in depth by entering the retail premises, frequently briefly interviewing shop staff. Towns were chosen primarily to view a reasonable range of sizes, and secondarily on the basis of accessibility. All surveys were carried out in August and early September 2005. Temperatures varied considerably during survey days, but were typically in the range 18 - 23°C. The cities chosen are located in two distinct climatic regions, Leicester, Chesterfield and Stamford, having cooler summers when compared with London. The regional cooling degree-days for England's Midlands is below 50 whilst for the Thames Valley region it is between 50 to 100.

Stamford, a small market town in the Midlands degree days region of England with a population of 18000, was the first town to be surveyed. Of particular interest in this town was widespread use of standalone pedestal fans for cooling. Special note was also taken of shop lighting types, which may prove particularly useful data to gather during future surveys.

The next town to be surveyed was Leicester, with a population of 280,000, although it is the main local commercial centre for around 0.6 million. In the central urban regions, several streets were surveyed, mostly in the city centre. Care was taken to ensure a mix of shopping areas (e.g. low cost areas, prestige city centre, financial district, etc.). Almost 100% of the premises have been photographed, such that building age, construction, and other details can be gauged from pictures at a later stage. The Leicester portion of the dataset is currently the largest, and is growing in depth, since we are finding extra streams of incoming data with which we can add functionality to the dataset as a whole, usually post-survey. A good example of this is that UK Government Valuation Office data is being connected to the Leicester Shop AC data, for computation of floor areas.

London is located in the Thames Valley region where the greatest concentration of air-conditioning is found in the UK. Being in the South East of England its climate is largely influenced by the continental proximity and the added urban heat island effect. Summer temperatures can occasionally climb to more than 30°C. London has a population of around 8 million. London's West End has a high density of retail premises and is arguably one of the busiest in the EU. Primarily the central Charing Cross Road and Covent Garden areas were surveyed, taking in the retail districts around Oxford Street and Covent Garden, as well as the fashionable café and bookshop populated areas to the East of the districts of Theatreland, and Soho.

Chesterfield is a larger market town, with a population of 100,000, towards the North of England, which is some 20 miles south of the city of Sheffield. It was chosen as a particularly average UK town. Chesterfield is generally not considered as a 'commuter town' such as towns of this size further towards the South East of the UK may be, and has a more average mix of population than Leicester. During these surveys information such as the shop's location, building orientation, presence of air conditioners, air curtains, fans and lighting types was collected.

2.2. Air conditioning usage intensity assessment

Temperature and RH probing was conducted in 20 different high street shops in London, on a hot summer's day, with an outdoor temperature of around 24°C. To proceed with the measurements the surveyor walked around the shops carrying two portable data loggers inside of a small well ventilated hanging fishnet bag. The loggers were set to record every 5 seconds. Each survey took an average of 10 minutes, to allow for the response time of the data loggers.

3. Results

The results shown in this section are drawn from a dataset of 607 premises. A reduction on the originally surveyed figure of 698 is imposed for the purposes of accuracy. This is because uncertain results, where even shop staff could not determine if air-conditioning was used on the premises, and results for premises in shopping centres which may be centrally air-conditioned and do not face the street, have been removed. Figure 1, shows the distribution of NESW orientation for ACs. Furthermore, AC use is fairly evenly distributed for orientation, with solar gains for South facing buildings, for example, apparently having little effect on the spread of results.

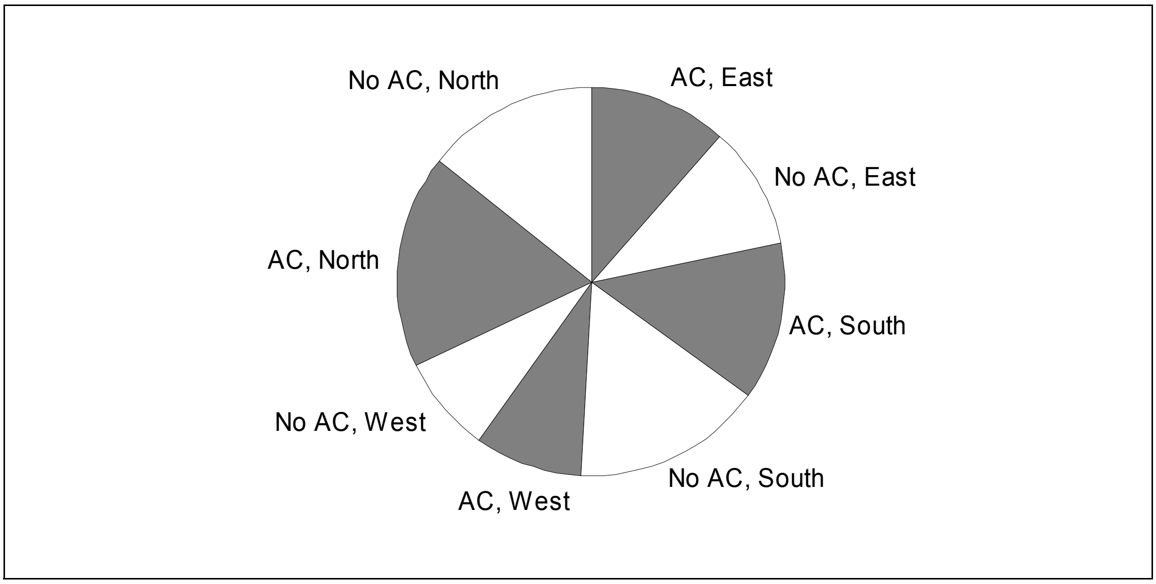

Figure 1 - North, East, South, West Distribution

Figure 2, shows distribution of shops for chain/local types. Some franchises are more conformist than others, but it is unlikely that energy management is as strict as in large chains. Typically, chain shops are larger, than locally owned shops, but this is not a definite rule.

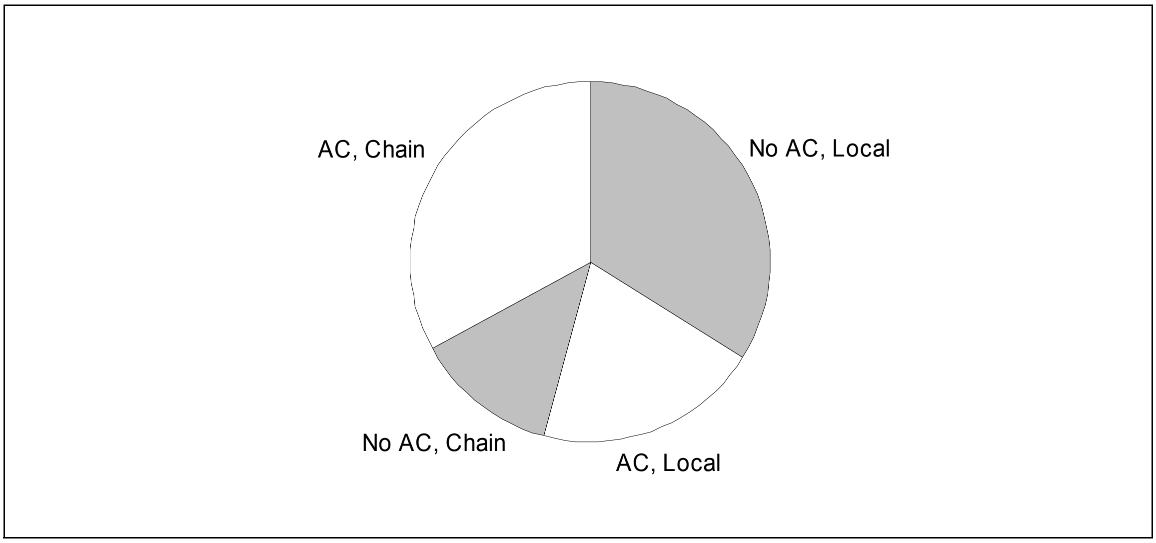

Figure 2 - Distribution between chain and locally owned shop AC use

Figure 3, shows the instances of AC use by town. It is interesting that the proportion of AC use in London greatly exceeds that of the other towns. Also of note, is the small sample size for Stamford, which is limited by the number of retail premises in the town. Finally, the proportion of premises using AC / no AC for Leicester and Chesterfield are fairly even.

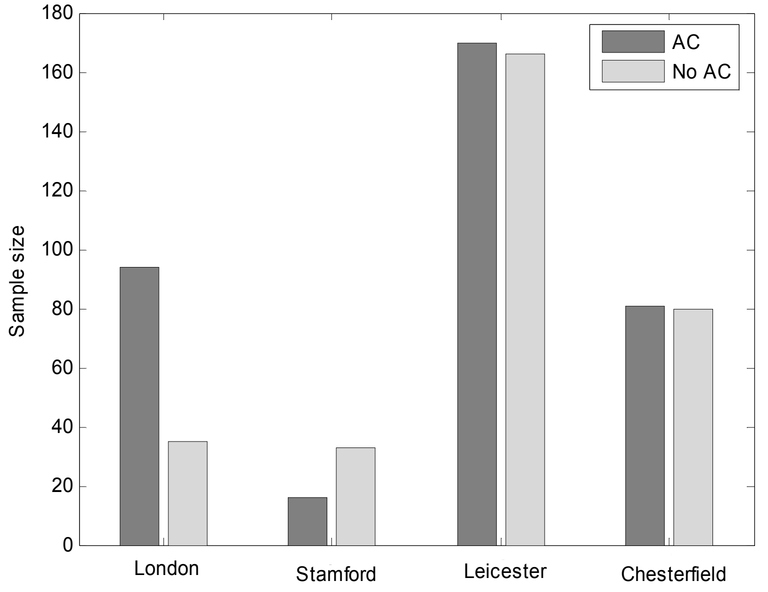

Figure 3 - AC vs. no AC by Town

Figure 4, shows the proportions of AC configuration and installation from the dataset for shops which are not in shopping malls. Rapid savings in energy could be made just by switching the air curtains on which are present in many doorways, to a 'cold' setting. A summary of these results is given in Table 1.

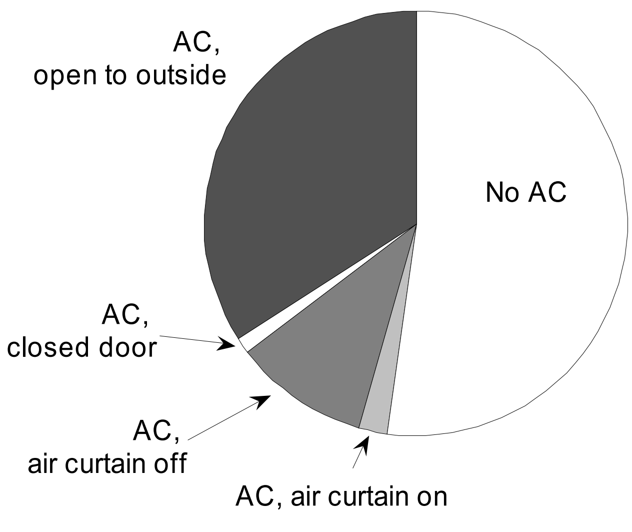

Figure 4 - Proportion of shops with AC, no AC, and Energy Conserving Measures

Table 1 - Summary of results

AC configuration	Number of samples	Percentage of total
No AC	317	52
AC, Air Curtain Off	62	10
AC, Air, Curtain, On	13	2.1
AC, Closed Door	8	1.3
AC, Open to Outside	207	3.4

Figure 5, shows the evolution of indoor air temperature and RH against time for some of the shops surveyed, as recorded by a datalogger. The lighter and darker curves show temperature and RH evolution respectively. Measurement periods inside air conditioned premises are characterised by a fast drop in temperature and a rise of RH. It is believed that the temperature drop would in some cases become even more pronounced if the dataloggers had a quicker response time. The periods indoors are identified as 'I's and outdoors as 'O's on top of the chart. Each period was also identified with a letter. The upright lines were drawn to ease interpretation of the graph, and to outline each one of the periods. It should be noted that while outdoors the dataloggers were sometimes exposed to solar radiation leading to a rise of the recorded temperature above the ambient temperature.

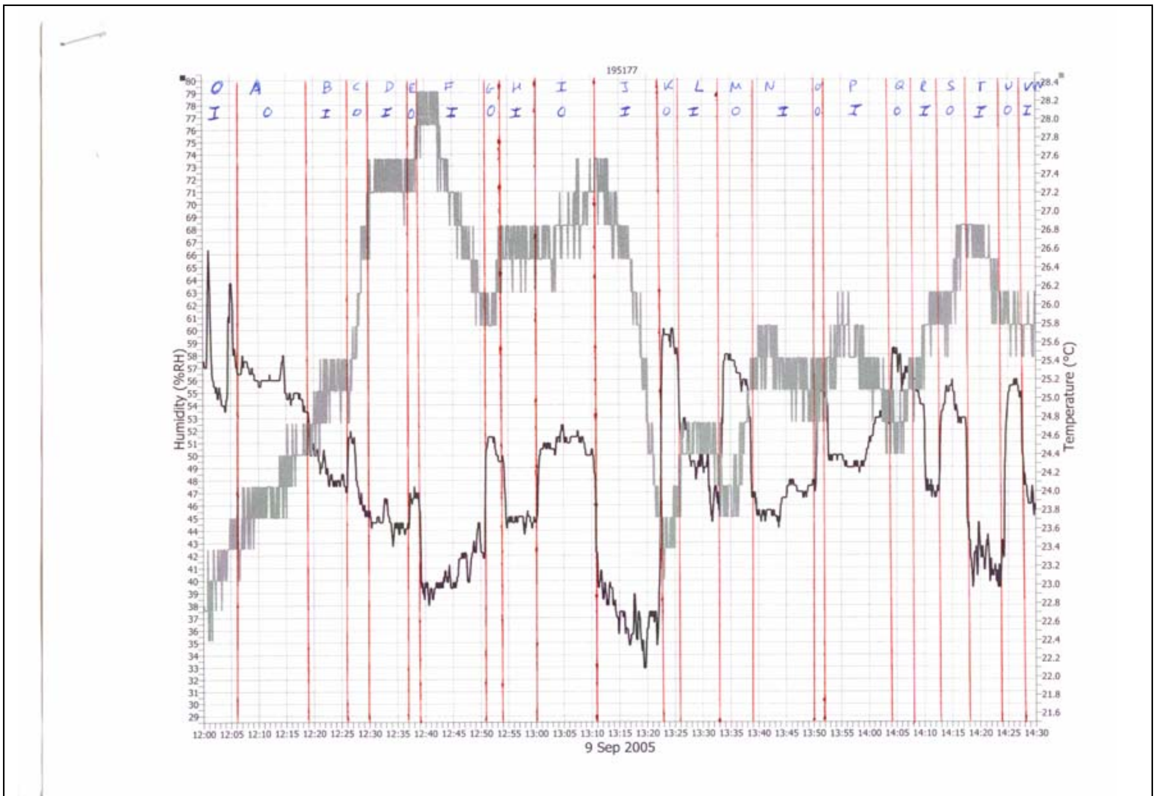

Figure 5. Evolution of temperature and RH in shops

The graph clearly shows a marked drop of temperature in some retail premises, i.e. shop J, indicating how heavily air conditioned they were. It was found that supermarkets generally registered the lowest indoor temperatures as a result of intensive use of air conditioning combined with open display refrigerators. The measured indoor air temperatures were found to be in some cases, well below generally accepted thermal comfort standards. This may eventually be designed to slow down the decay of perishable goods and to ensure a longer shelf live while retaining ready access to displayed goods. On the other hand, by setting air conditioners at lower temperatures, in fact the energy efficiency is decreased without any real improvement of the indoor environmental quality. The findings of this investigation were compared with datasets from different sources that show that energy intensity in supermarkets is in fact about twice than that of other retail stores.

4. Discussion and future work

It must be remembered that this is a pilot survey, and the first of its kind. The next step is to design a much larger follow-on to the 2005 AC survey. This would have two purposes Firstly to re-visit the same sites, and secondly, to look at the spread, or otherwise, of AC usage, and to expand the survey to include more premises and more towns.

Two additional types of survey could be carried out, in order to populate the existing dataset with useful extra data. 'After dark surveys' - looking at usage of display lighting etc, but also *after shop closing* - i.e. Sunday evening, to examine which premises have many lights burning. 'Winter surveys' of the same properties may also be carried out, to examine energy saving measures employed during the cooling season. Of particular concern, is accidental use of cooling by retail premises during the heating season. Both heating and cooling systems are, in effect, in competition. Indeed, it is not unknown for occupants of some offices to use AC's in winter in overheated rooms, since they have no heating control, or openable windows, and we may find a similar situation in retail.

Tests have started to be carried out using high resolution Infrared (IR) cameras. The aim is to investigate not only the use of air conditioning in retail premises but also whole blocks of buildings. Eventually aerial IR photos will be taken in the future if it is found that rooftop heat dissipation units are distinctly visible from relatively long distances. Heat leakage through open doors and windows in air conditioned buildings is also to be investigated and by using CFD techniques could eventually be quantified.

5. Conclusions

In this paper are presented results from a survey that is believed to be statistically representative. Nevertheless it was a fairly small survey of UK retail premises and larger follow-on surveys are to be conducted during the summer of 2006. Future research will investigate the effects on energy consumption of the energy management practices observed. This work will include obtaining floorspace data for the surveyed premises and modelling energy use to estimate incremental energy consumption. These early results however, show that the use of air-conditioning in retail premises in the UK is extensive, and in some cases excessive, where temperatures are uncomfortably low. The results show that the use of energy saving measures during the cooling season, such as closing external doors, or using air curtains, is minimal.

6. Acknowledgments

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The Components of Heating and Cooling Energy Loads in UK Offices, with a Detailed Study of the Solar Component

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Abstract:
The AuditAC[1] project is producing information which will enable the energy efficiency of Air Conditioning Systems to be improved through Audits and Inspections. Part of the basic information the project will produce is guidance on the type of loads imposed on the AC systems by the building and occupancy characteristics.
The driver for this is Article Nine of the European Directive on the Energy Performance of Buildings which requires “regular inspection” of all systems above 12kW rated output. Part of the inspection is also to determine if the required cooling loads can be reduced or met by alternative solutions such as solar shading devices and more effective glazing systems.
Following on from 2 previous papers presented on the energy use of Air Conditioning systems at IEECB 2004[2,3], this paper presents an initial overview of the relative importance, amplitude and time-varying nature of the components of the heating and cooling load found in a UK Office. These components have been obtained using the modelling methodology outlined in another IEECB ’06 conference paper[4] and are semi-empirical in nature.
The load components presented are the ‘internal gains’, ‘ventilation and infiltration’, ‘fabric’ and solar components, and have been derived from the modelling of one Office from the original Welsh School of Architecture “AC Energy Use in Offices: Field Monitoring Study”. Information of this nature will be invaluable in assessing which actions might initially be the most effective in reducing the energy consumption of heating and cooling systems in UK Offices by measures such as solar shading and glazing treatments, as it shows how much of the total heating and cooling load we might expect to meet through such actions.
The paper then goes on to examine the nature of the Solar Component in UK Offices.
The methodology used in the two analyses will be used to inform the AuditAC study and, as a result, the guidance to be provided for countries other than the UK.

Breakdown of the Heating and Cooling Loads on UK Office A/C Systems
This section of the paper shows how the loads imposed on the heating and cooling systems vary in a particular UK Office building. The aim is to establish the main sources of the loads, and their relative importance, with the ultimate aim to be able to advise designers of buildings and A/C systems on the issues which will affect the heating and cooling loads in the building and hence the energy needed to maintain comfort conditions.

Modelling Issues
Based on Bleil de Souza[4], we have already seen that two different modelling tools can reasonably accurately describe the internal temperatures achieved within a real building, with all the uncertainties associated with the operation of a real building. This finding implies that the same models would therefore also be able to predict where the loads in the building come from, and this section of the paper deals with these load predictions.

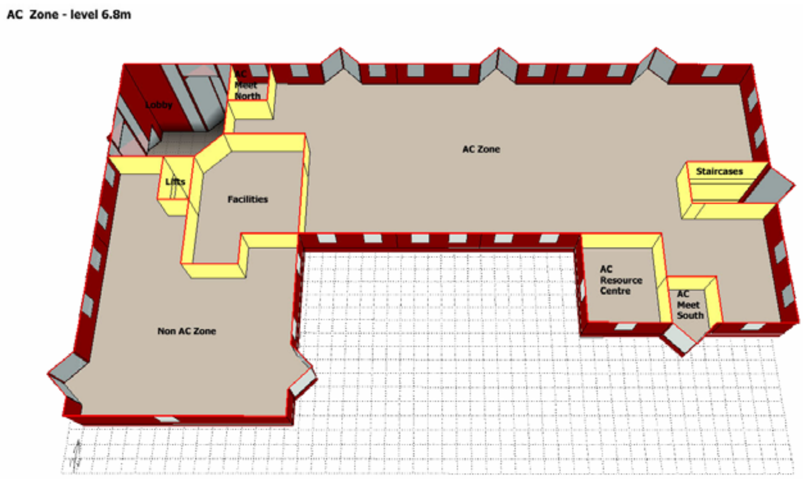


Figure 1. ECOTECT model of example building

The following tables and graphs show for one UK Office building, depicted in Figure 1, how the overall loads on the building heating and cooling systems are 'built-up' in terms of the 'internal gains', 'ventilation and infiltration', 'fabric' and solar components. The 'baseline' modelling input figures for this building are the 'average' values for all the building components and parameters as shown in Table 1.

Table 1. Average and range of input values for the modelling parameters

Group		Minimum	Average	Maximum
Air changes				
	Ventilation Rates	8 l/s person	16 l/s person	36 l/s person
	Infiltration Rates	0.15 ach	0.35 ach	1.25 ach
Internal Gains				
	Activity levels	115 W/person	130 W/person	140 W/person
	Lighting levels	-	9.79 W/m^2	11.5 W/m^2
	Small power Rates	9.26 W/m^2	21.38 W/m^2	37.02 W/m^2
Materials				
	Glass transmittance	0.228	0.565	0.901
	Glass conductivity	0.604 W/mK	1.294 W/mK	1.984 W/mK
	Wall insulation conductivity	0.025 W/mK	0.039 W/mK	0.053 W/mK
	Ceiling insulation conductivity	0.025 W/mK	0.039 W/mK	0.053 W/mK

The heating and cooling set-points in the building are 21°C and 24°C respectively, and the cooling load calculations occur only for the occupied periods which are from 08:00 to 18:00, Monday to Friday. The cooling loads presented are the sum of the 'purchased air' loads as predicted at 15 minute intervals by the EnergyPlus software tool. The loads shown are those that would be imposed on any heating or cooling system which may be installed, and do not therefore include any issues to do with system design, system efficiencies, etc. The loads were also produced in response to the measured weather data for 2001 for the location.

Modelling Results – Average Parameter Values

Figure 2 graphically presents the breakdown of the predicted overall monthly loads on the heating and cooling system in this Office building based on inputting the average values for the main parameters in the building as shown in Table 1. A negative figure indicates a heat loss from the space, i.e. a load on the heating plant. The energy balance requirements to meet the heating and cooling setpoints are also shown on this graph as the white portion of each stacked bar.

It should be noted that all the predicted loads are also based on ideal control and unlimited capacity in the heating or cooling systems. The results presented are for the sensible cooling loads only, as there is no humidity control available on the A/C system in this building.

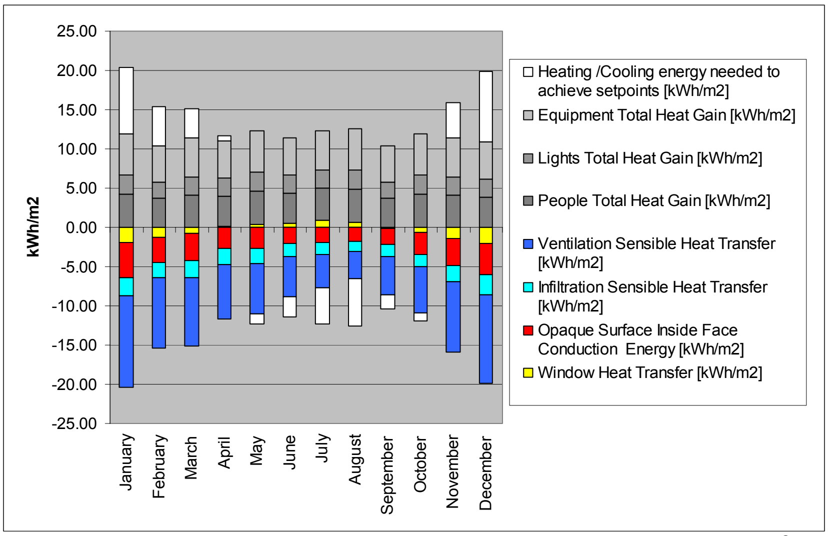


Figure 2. Average monthly heating and cooling load in kWh/m^2 broken down by component.

It can be seen that the overall load on the building changes from a requirement for heating in April to a requirement for cooling in May. The overall load reverts back to a heating load in November. The total cooling requirement over the Summer period is 17.0 kWh/m^2.

In terms of magnitude, the largest average energy **gains** to the modelled space are clearly the people and equipment loads which are roughly the same size. The other major load is the Lighting which is approximately half the size of each of these two previous loads. The only other energy gain to the space occurs through the window heat transfer component during approximately 4 months of the year in the Summer. This energy gain is on average very small in comparison to the other gains.

The average monthly energy **losses** to the modelled space are dominated by the ventilation component which is generally greater in magnitude than all the other losses combined. The other energy losses are, in order of decreasing magnitude, due to losses through the fabric (opaque surface inside face conduction), infiltration and window heat transfer components.

In terms of **variation**, it is seen that the internal gains (people, lights and equipment components) do not show much variation over the year, reflecting the 'hot-desking' nature of the occupancy in this space, and also highlighting potentially poor lighting control over the Summer period. The load components that show the largest variation over the year are the ventilation, infiltration and fabric components. The window heat transfer component, which includes solar gains, shows the lowest variation. This component is examined in more detail later.

Modelling Results – Sensitivity Analysis
A full analysis of the effect of varying each of the modelling parameters individually across their likely range in this building has been undertaken, with all the other parameters kept at their average value during the analysis. Table 1 shows the ranges of values for each parameter.

Table 2 shows the effect that each variation had as a percentage of the predicted overall kWh/m^2 load for each month.

Table 2. Percentage variation of predicted overall monthly load from varying individual parameters

Parameter varied:	Ventilation	Infiltration	Occupant Activity Level	Lighting	Small Power	Solar Transmittance	Window Conductivity	Opaque fabric conductivity	Ceiling conductivity
January	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**
Min	-68%	-14%	5%	N/A	32%	1%	0%	-2%	-3%
Max	172%	52%	-3%	-4%	-40%	-1%	0%	2%	3%
February	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**
Min	-85%	-18%	7%	N/A	47%	4%	-1%	-3%	-4%
Max	220%	67%	-5%	-5%	-55%	-4%	0%	2%	4%
March	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**
Min	-100%	-24%	10%	N/A	66%	9%	-1%	-3%	-5%
Max	283%	91%	-7%	-7%	-69%	-8%	0%	3%	4%
April	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**
Min	-310%	-96%	45%	N/A	301%	68%	-3%	-12%	-14%
Max	1124%	385%	-30%	-30%	-236%	-58%	1%	10%	12%
May	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**
Min	179%	39%	-24%	N/A	-134%	-34%	1%	5%	4%
Max	-457%	-150%	16%	14%	172%	29%	0%	-4%	-4%
June	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**
Min	90%	23%	-13%	N/A	-50%	-19%	1%	3%	1%
Max	-111%	-52%	9%	9%	110%	21%	0%	-2%	0%
July	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**
Min	43%	15%	-9%	N/A	-46%	-15%	1%	2%	1%
Max	-65%	-39%	6%	7%	70%	16%	0%	-1%	0%
August	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**
Min	27%	10%	-7%	N/A	-40%	-10%	0%	1%	1%
Max	-42%	-27%	5%	6%	57%	10%	0%	-1%	-1%
September	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**
Min	114%	28%	-16%	N/A	-69%	-16%	1%	4%	4%
Max	-178%	-69%	12%	11%	138%	17%	0%	-3%	-3%
October	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**
Min	198%	37%	-27%	N/A	-138%	-17%	1%	5%	8%
Max	-445%	-130%	18%	16%	210%	14%	0%	-4%	-7%
November	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**
Min	-89%	-21%	9%	N/A	58%	4%	0%	-3%	-5%
Max	248%	78%	-6%	-7%	-58%	-3%	0%	3%	5%
December	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**
Min	-63%	-14%	4%	N/A	28%	1%	0%	-2%	-3%
Max	157%	49%	-3%	-3%	-35%	-1%	0%	2%	3%

The main observations from Table 2 are that, within the likely range to be found within this particular building, the parameter ranges that have the greatest effect on the loads within the space are the ventilation rate, the infiltration rate and the equipment loads (small power in the table). In some cases this range of variation is sufficient to change the overall requirement in the space from a heating to a cooling load or vice versa. This is particular true for the ventilation rate variation, the figures for which are shown graphically in Figure 3.

The figures shown in bold in Table 2 are the normalised overall heating or cooling energy needs for that month to reach the thermostat setpoints. A negative figure indicates that the space needs heating by the amount of energy shown. A positive figure indicates a need for cooling.

A positive % figure in the table indicates the percentage by which the monthly overall load figure increases as a result of the indicated change made in the parameter. A negative % figure indicates that the monthly overall load figure is reduced by that %. A negative figure greater than 100%, such as that for the maximum ventilation rate in May, indicates that the overall load is changed from, in this example, a cooling load to a heating load.

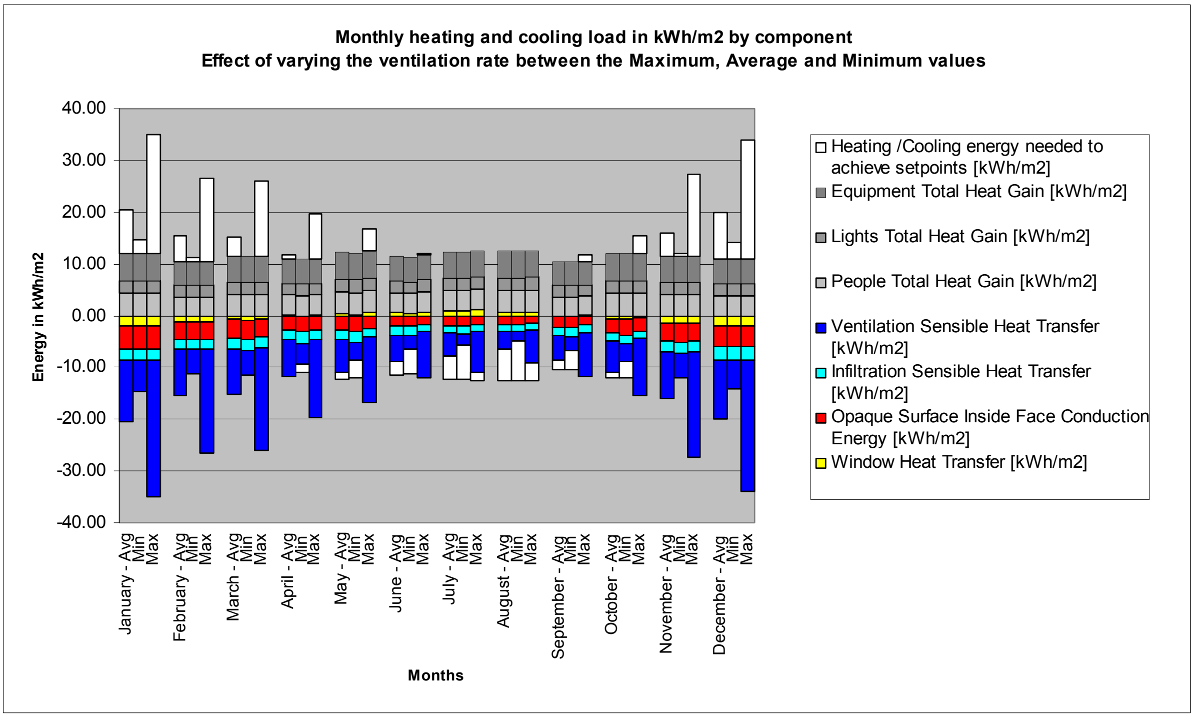


Figure 3. The effect on the monthly heating and cooling load, in kWh/m^2 per component, of varying the ventilation rate parameter between its Maximum, Average and Minimum values

The range of ventilation rates used are those that might be encountered in Offices according to CIBSE guidance[5]. In this case the Minimum ventilation rate was set at 8 litres/second per person (l/s/p), the Average ventilation rate at 16 l/s/p, and the Maximum ventilation rate at 36 l/s/p.

This figure holds a lot of information about the performance of the building under varying ventilation rates. For example, we can see from the range of white bars on the graph that, within this range of ventilation rates, cooling could be required between 2 to 7 months of the year depending on the ventilation rate chosen. The heating requirements could also be varied from 4 to 10 months per year.

Modelling Results – Solar Component

The overall window heat transfer component in this building is shown not to have a huge effect on the overall heating and cooling requirements, but we will examine it in more detail as this component may be more important in other buildings both in the UK and Internationally. Figure 4 shows how the window heat transfer component can be further divided into solar and non-solar components. This reveals how the two components interact over the year, and shows the relative importance of the window conductivity in assisting cooling in this building over the Summer period.

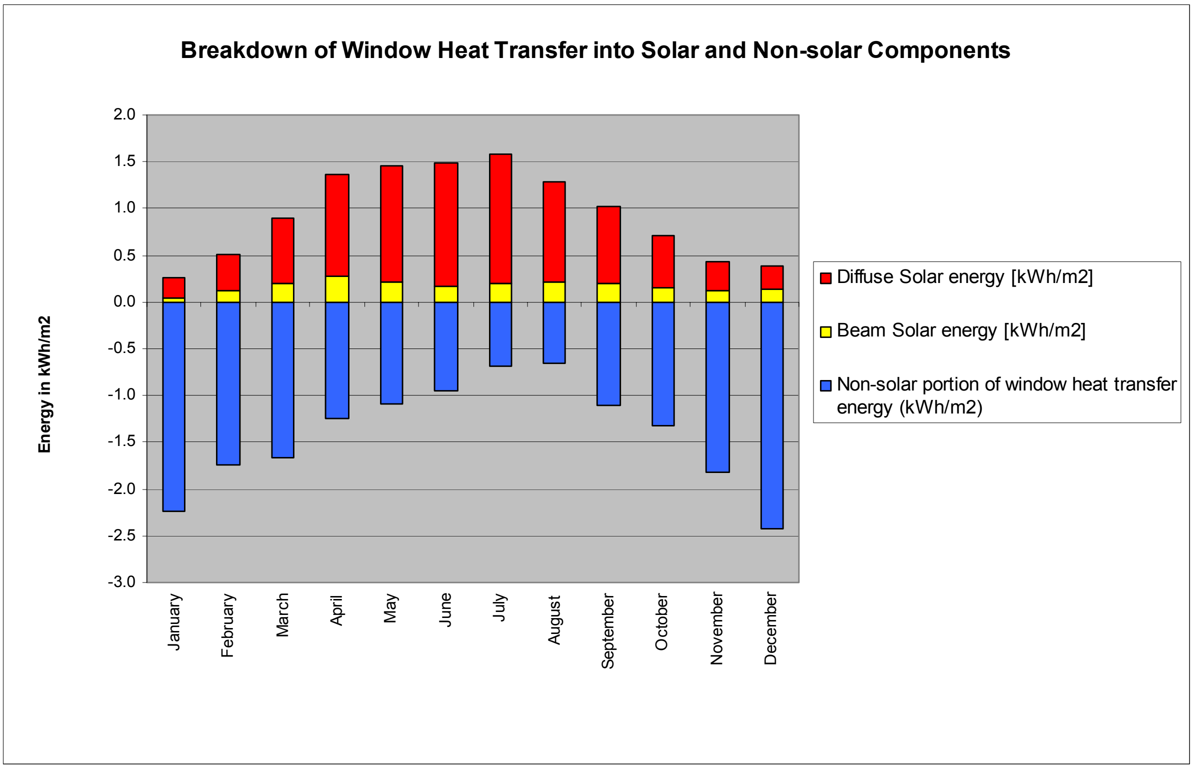


Figure 4. Breakdown of Window Heat Transfer into Solar and Non-Solar Components

The direct or beam solar gains are a relatively small component in the Air Conditioned zone modelled, as Figure 1 shows that there is not a great deal of glazing that would be in direct sunlight as the majority of the glazing is located on the North wall. The majority of the solar gains are therefore diffuse.

The second half of this paper discusses the area of solar gains in more detail, with particular attention to the effect that various solutions may have on daylighting levels. Artificial lighting gains, while only about half the equipment and people gains, are an important area for attention as daylight-linked control of these systems to a 500 lux level as recommended by CIBSE[6] for this type of space could reduce the heat gains from lighting by 80%[7].

Overall Breakdowns Conclusions

The overall conclusions for this building, based on the average values for each of the parameters, are:

- Over the entire year the building heat gains are dominated by equipment and people, with lights also being important. The building heat losses are dominated by the ventilation component, with fabric losses also being significant.
- As the gains from equipment and people have a large effect on the loads to be met by the systems, so the demands imposed will be heavily dictated by control of these factors. Assuming that we have no control over the occupancy then the area that would most benefit from attention in trying to reduce the cooling load would be the equipment load over the Summer.
- External conditions mean that on average the air change and opaque fabric components in this building always lose heat to the surroundings throughout the year.
- The window heat transfer components on average play little part in the overall energy balance in the building, i.e. solar gains appear to have little influence on overall energy requirements in this building.

- Good control of the ventilation and infiltration components, linked with heat recovery in the winter, would appear to provide opportunities for minimising or eliminating heating and cooling needs in this building.
- Fabric losses play an important part in the heating and cooling needs for the building, and a more detailed analysis could be undertaken to find the optimum insulation and thermal mass levels needed to obtain the correct balance between reducing the Winter heat load on the heating system, yet retaining the Summer heat loss which is beneficial in reducing the cooling load.

Solar Shading systems and Their Relative Effect on A/C Loads

This section of the paper considers how solar shading in a building affects the loads on the AC system. From the previous section it can be seen that internal lighting gains in the Office modelled are a significant load on the A/C system in the summer period. On the other hand, based on climate data for Cardiff and the specific configuration of the building, direct solar gains are much less significant. If, as is the case throughout the UK, daylight can be used to offset a major portion of the internal lighting loads, then the design of the solar shading is often as much about admitting the right amounts of daylight as it is about keeping out unwanted solar gains. Obviously in hotter and sunnier climates the relative influence of each will vary.

As most commercial buildings use manually operated vertical blinds and other internal shading devices to reduce direct solar gains and glare, the relationship between solar gain, overheating and daylight can be a complex one. This is due to occupant control and because the exact nature of their installation and the existence of pelmets and window vents have a significant effect on their thermal performance, something that is discussed in detail in the following sections. It is therefore important to consider the exact nature of installed shading systems and subject them to simulation methods that fully account for convective and radiative effects as well as conduction.

As auditors are unlikely to use complex numerical simulations of each building, to accurately judge the potential of changes to shading and glazing they will need to rely on some very general characteristics of each building they assess and the climate in which it sits. However, the true effects of solar gains on overheating in buildings depend not only on external characteristics such as window size and orientation, but also on the properties of the internal surfaces they strike – be they floors, walls or even blinds and curtains. These effects determine the ratio of instantaneous space gain to stored fabric gain, a characteristic fundamental to the response of each room.

The aim of this part of the paper is therefore to describe the methodology used to determine those internal building characteristics that most affect solar overheating. EnergyPlus[8] has been used to undertake a series of parametric analyses on the single office building shown in Figure 1 and the comparative results are presented. **Whilst in the case of this specific building the effects of solar gains are relatively small, the intention is that the methodology will be applied to a range of buildings using different hourly climate data sets from across Europe**.

The parametric study considered the relative influence of the following factors:

- window size and glazing type,
- external shading systems,
- internal shading systems and associated convection coefficients,
- levels of exposed internal thermal mass, and
- perimeter zoning within the simulation model.

The Basics of Internal Solar Shading Design

In many building regulations and simplified analysis methods, solar effects on buildings are characterised only by the exposed area of glazing and type of glass used. This is used to give a measure of solar gains entering the building, effectively a simple solar aperture value. However, the true effects of solar radiation on internal conditions within a space are much more complex. The following is an examination of the factors that affect the influence of solar radiation on internal energy loads.

Window Size and Glazing Type

In terms of analysis, window size and glazing type are almost the same thing. Large areas of glass with a low solar transmittance are effectively the same as a lesser area of glass with a proportionately higher solar transmittance. Thus the effective area of glazing is usually given by multiplying its physical area by its average solar transmittance.

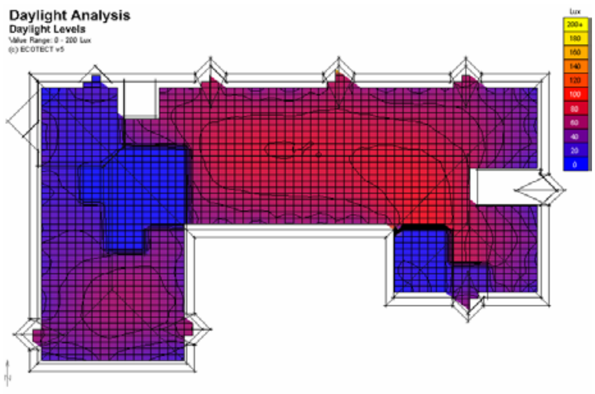
In these cases, solar transmittance is given as a solar heat gain coefficient (SHGC). This refers to the ratio of solar heat gain actually entering a space through a window compared to the total incident solar radiation falling on its outside surface. This includes both directly transmitted solar heat and the solar radiation actually absorbed by the glass, which is then re-radiated, conducted or convected into the space. This is an important point as some older tinted glasses claimed a very low solar transmittance by suspending metal particles as part of the pigment within the glass. When subject to solar radiation however, these would absorb a significant portion of the gains which would heat the glass up quite considerably. Whilst the direct sunlight travelling through the glass was relatively low, a large portion of the solar gain was still conducted to the inside surface of the glass and then radiated and convected into the space behind.

Unless the transmittance of a glass is given as a SHGC, care should be taken about claims of high performance. Table 2 gives some example SHGC values for a range of different window and glazing types.

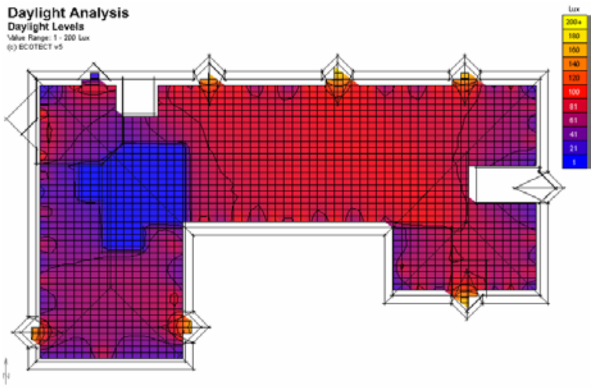
Table 2. Some example solar heat gain coefficients[9]

Glazing Type	SHGC
Single Glazed, Clear Float	0.86
Single Glazed, Bronze or Gray Tinted	0.73
Double Glazed, Clear Float	0.76
Double Glazed, Bronze or Gray Tint	0.62
Double Glazed, High Performance Tint	0.48
Double Glazed, High Solar Gain, Low-E	0.71
Double Glazed, Moderate Solar Gain, Low-E	0.53
Double Glazed, Low Solar Gain, Low-E	0.39
Triple Glazed, Moderate Solar Gain, Low-E	0.5
Triple Glazed, Low Solar Gain, Low-E	0.33

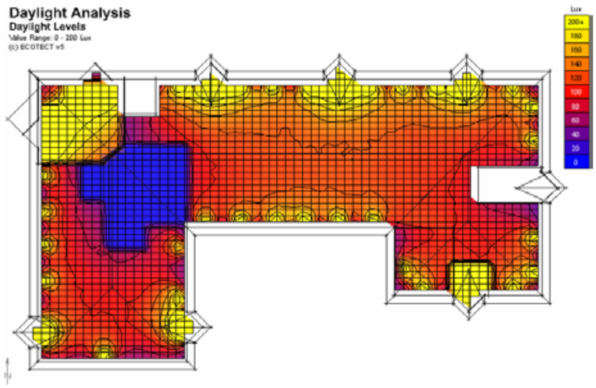
In many glasses, the SHGC is related to visible transmittance. This essentially means that any reduction in solar gain passing through the window with a low SHGC is accompanied by a similar reduction in the amount of visible light transmission, resulting in reduced internal daylight levels. There are some recent spectrally selective glasses in which this effect is less noticeable however, as shown in Figure 5, the effect of variation in the visible transmittance of glass on internal daylight levels is significant. These figures were obtained under an overcast sky of 4500 lux.



Visible transmittance: 0.25



Visible transmittance: 0.50



Visible transmittance: 0.75

Figure 5. The effect of glazing visible transmittance on internal daylight factors.

Varying the SHGC simulates the effect of using either different solar control glasses or applying a perforated metal mesh, a shade screen or other semi-transparent external shading systems. Figure 6 shows the results of a parametric analysis in which the SHGC of windows on the south, east and west façades was varied from 0.1 to 0.9 in steps of 0.2. The metric used for comparison was the total annual heating and cooling loads per square metre floor area.

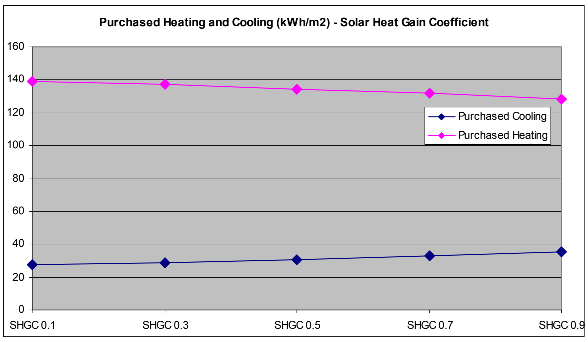


Figure 6. The effect of external shading devices on total annual heating and cooling loads per square metre floor area.

In the building studied here, increasing the SHGC increased the total annual cooling load whilst at the same time reducing the total annual heating load, with an overall annual variation of less than 2%.

External Shading and Solar Protection

If there is an opaque obstruction between the sun and a window, direct solar gain will be blocked – being either absorbed or reflected by the objects that form the obstruction. Diffuse radiation from the sky and reflected radiation from the ground and other external surfaces may still get through.

Of all the available options, external shading devices usually work best. This is because they prevent the gains from hitting the window in the first place. To reach internal blinds, louvres or curtains, the solar radiation must already have passed through the window. Whilst it is then blocked by the internal obstruction, it is still incident on that obstruction so the energy acts to increase its surface temperature. Under direct sun, temperatures in the air gap between a blind and the window may be up to 20°C higher than average internal air temperatures.

In many buildings a combination of external and internal shading systems are used. This is primarily to combat glare at times of low sun angle. Badly designed external shading can often result in people keeping the internal blinds closed throughout the day, requiring the electric lights to be turned on to make up for the reduction in light levels. The means a double load – more gains to the space through solar radiation on the blinds and more heat from the extra lights. This indicates again that, at higher latitudes where the sun is lower in the sky, good solar shading design is not just about solar protection but also preventing external glare and at the same time maximising internal daylight.

There are many different types of external shading device, each with their own performance profile reflecting the changing position of the sun both hourly over the day and seasonally over the year. Some systems, such as fixed horizontal shades, will have poor performance when the sun is at a low altitude but very good performance when it is high overhead. On south-facing facades this effect can be exploited to allow solar gains in winter whilst fully protecting in summer. Other external shading systems such as perforated metal mesh can be configured to be independent of solar position, providing the same level of protection throughout the year. Further still, systems such as shutters and rollers can be deployed dynamically by the occupants to accommodate hourly solar variation.

To effectively examine these effects it is necessary to compare extreme examples of each case. Thus, in addition to the SHGC simulation described previously, the following two analyses have been performed:

- Variation in horizontal shading depth directly above windows on the south, east and west facades. In these cases a horizontal plane running the full length of each façade was generated at depths of 200mm, 500mm, 1000mm, 1500mm, 2000mm.
- To represent dynamically deployed shading systems such as shutters or rollers, calculations were performed such that the shading was engaged on each window when the incident solar radiation exceeded a given threshold value. Calculations were performed for thresholds varying from 100W/m² to 600W/m² in steps of 100W/m².

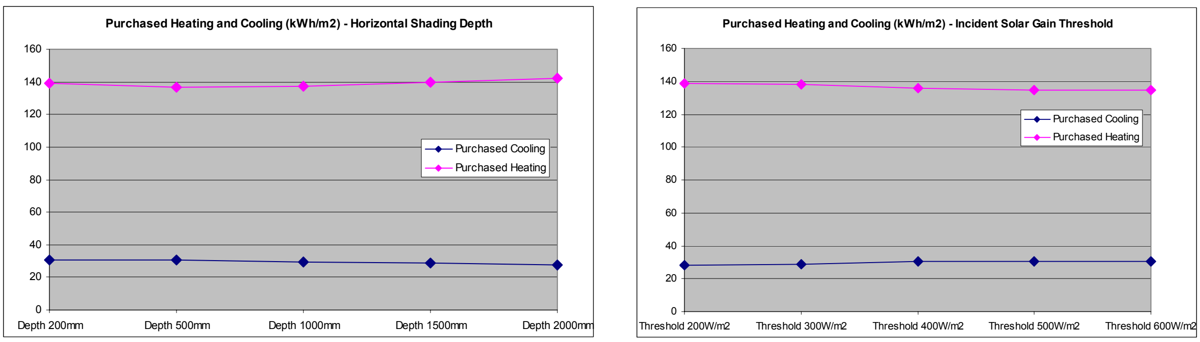


Figure 7. The effect of external shading devices on total annual heating and cooling loads per square metre floor area.

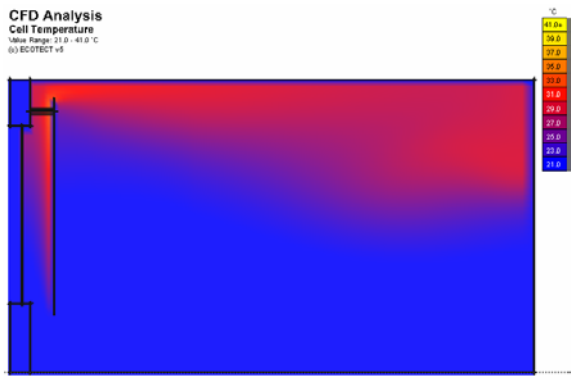
The results show that, whilst varying these parameters has an effect, annually it is less than 1.5%.

Internal Shading

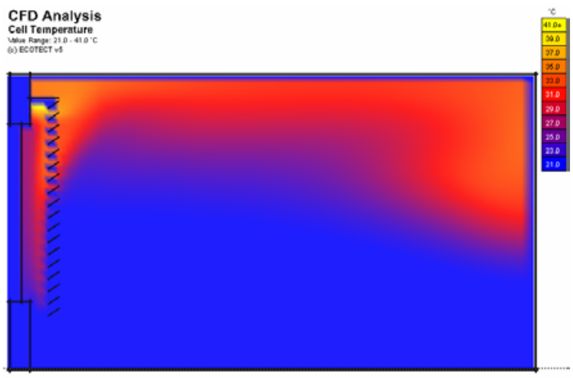
Once solar gains have passed through a window and hit an internal blind, they are already effectively inside the space. Only if the blind surface is highly reflective and the solar rays redirected straight back out the window will this not result in some heat internal build-up. Thus, whilst the blinds may effectively block glare and daylight, the effects of conduction, convection and radiation will usually convey almost all the heat into the space.

If the area between the blind and the window is open at top and bottom, a convection current will likely result with warm air rising out the top drawing cool air in from the bottom. Such a system is a very efficient heat transfer mechanism which can be used to good effect in winter, but is rarely desirable in summer. This can be ameliorated to some extent using pelmets and full-length blinds, as well as controllable high level vents at the top of the window to duct the rising warm air to the outside.

The true thermal effect of an internal shading system therefore depends greatly on the detailed nature of the air flow it induces. However, a typical thermal analysis will only consider its opacity and any additional insulating characteristics it imparts to the window. To properly consider convection effects requires a detailed 3D model of the window-blind configuration and a complex computational fluid dynamics (CFD) solution.

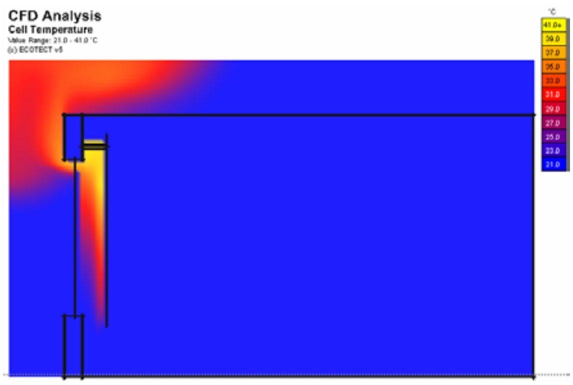


Vertical blind open at top and bottom



Horizontal louvres

Vertical blind with sealed pelmet at top



Vertical blind with pelmet and window vent

Figure 8. Example images from a computational fluid dynamics analysis of a range of internal shading systems showing internal temperatures distribution resulting from 660W/m² of incident solar gain on the window.

Figure 8 shows some example images of such a CFD solution for a range of different internal shading devices after 15 minutes of exposure to 660W/m² of incident solar gain. However, even with such detailed analysis, it is very difficult to calculate an accurate convection coefficient for each blind assembly as the systems are essentially dynamic feed-back loops, changing in efficacy as warmed air re-circulates back in through the bottom. Similarly, the efficacy changes based on the amount of incident solar radiation, the solar absorption and emissivity of each surface and the flow resistance of both top and bottom openings.

Auditors are unlikely to apply such solutions at the level of detail required and manufacturers are unlikely to provide detailed data on the full range of potential installation configurations.

In order to determine the relative sensitivity of the calculations to variations in convection coefficients, three different internal shading configurations were used: a flat blind open at top and bottom; a flat blind with a sealed pelmet at the top; and a set of horizontal louvers set at an angle of 45deg. The vented window option shown in Figure 8 was not tested as, to effectively balance pressures in the room, an additional inlet vent would have been required along with a relatively arbitrary specification of inlet air conditions.

Computational fluid dynamics calculations were performed on the three configurations in order to determine air flow rates and exit point air temperatures. From this an estimation of the convection transfer functions was made for each system under high (660W/m²) and low (100W/m²) incident solar radiation conditions. Figure 9 shows the effect of the three internal shading configurations on total heating and cooling energy when applied to the test building. Future work in this study will consider the effects of dynamic internal shading on both energy and daylight, including a detailed analysis of variations in louver angle, percentage blind coverage and window venting.

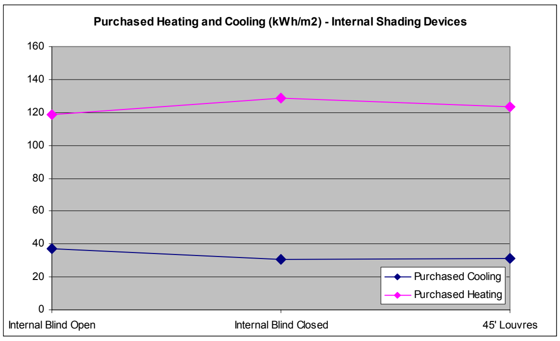


Figure 9. The effect of internal shading system on total annual heating and cooling loads per square metre floor area.

Even within a large conditioned zone, the results show that loads are sensitive to internal convection effects, with a total variance over the range of parameter values in the order of 5.3%.

Exposed internal mass

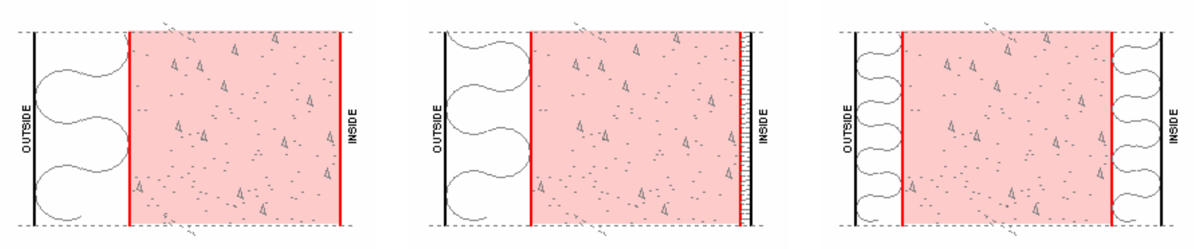
When solar radiation falls directly on the surface of a material, the incident energy acts to increase the surface temperature. As it does this, the temperature differential between the surface and the material immediately underneath also increases. This results in a flow of heat from the surface deeper into the material itself. The rate of this heat flow depends upon the conductivity of the material.

For most high thermal mass materials with high conductivity, this occurs faster than the surface heat can be lost by radiation or convection into the air layer immediately above it. This means that surface temperature rises remain relatively low with the heat energy quickly dispersed over a much greater mass of material. Inside a space, this means that both air and mean radiant temperatures remain relatively unaffected. However it also means the heat is stored within the fabric of the space for release later when internal temperatures fall.

For low thermal mass or low conductivity materials (i.e.: highly insulating), very little of the surface heat is conducted away internally. This means that the rise in temperature at the surface is much higher, leading to the majority of heat being lost immediately by radiation and convection. This has an almost immediate impact on both air and mean radiant temperatures within a space. This means that, with the appropriate choice of materials, the designer has significant control over the response of each space to internal and solar gains, suggesting the placement of carpets, tiling, wall-coverings and furniture all play an important thermal role that must be accounted for.

To determine the effects of internal exposed thermal mass, energy calculations were performed using three different material configurations. As EnergyPlus calculates the thermal response of each material based on the width, density, specific heat and conductivity of each of its component layers, the three different materials had to be constructed such that their overall thermal responses were equivalent in order that the comparison not be masked by differences in heat transfer coefficients. Additionally, the same material was applied to both the walls and the ceiling of all spaces in the building. The floor was assumed to be carpeted and not available as an exposed surface.

A standard concrete wall construction was used as the basis of each material, with compensating insulation layers on the inside and outside. The three levels of exposed mass were generated by varying the inside insulation layer and compensating with the outside layer, as illustrated in Figure 10. Analysis in EnergyPlus showed that U-values between the cases varied by less than 0.01 W/m²K.



Exposed Thermal Mass. *5mm Internal Insulation* *25mm Internal Insulation*

Figure 10. The component layers of the three materials used in the exposed internal thermal mass analysis.

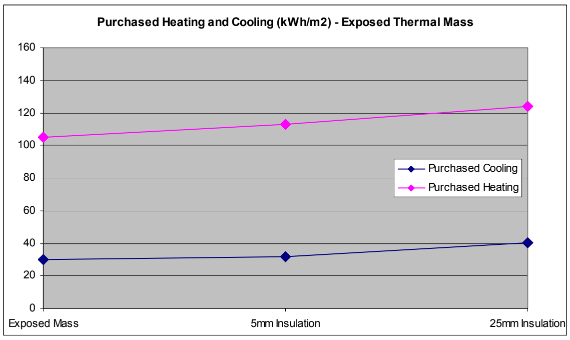


Figure 11. The effect of exposed internal thermal mass on total annual heating and cooling loads per square metre floor area.

Even within a large conditioned zone, the results show that loads are sensitive to internal convection effects, with a total variance over the range of parameter values in the order of 5.3%.

Zones and zoning

Almost all thermal analysis algorithms calculate a single temperature for each zone – this being the average over the whole space. This is calculated by summing all the gains and losses across the zone. If one part of a zone is subject to high solar or radiation gains, it is likely to have a higher local temperature. However, this will only be indicated by a slightly increased zone average, the specific localised temperatures in different parts of the zone will not be calculated.

If a large space were subdivided into a number of smaller 'virtual' zones, it would be possible to quantify these localised variations. Each calculated temperature will still be the spatial average for each 'virtual' zone, suggesting that ideally they should be as small as possible. However, each thermal analysis engine treats the interface between 'virtual' zones differently. Some use fictitious surfaces and require the user to specify heat transfer and inter-zonal air flow values. EnergyPlus requires that the interface between zones be physical, created as a resistance-only material or a large open window. Either way, these 'virtual' inter-zonal boundaries will affect both the flow of heat around the zone and the mixing of the air volumes – introducing inaccuracies into the calculation. Thus by creating very small 'virtual' zones near a window, the thermal analysis may not properly account for air movement across the space – meaning that it is likely to overemphasise the thermal effect of the solar gains. If you use very large 'virtual' zones, the same averaging effects will tend to underemphasise the solar gains.

Unfortunately there is no simple answer for the optimum zone size. As a result, it is important to know the extent to which different relative 'virtual' zone sizes affect solar gains in office buildings.

To investigate the effects of zone size, five 'virtual' zone configurations were used based on the perimeter depth around the building. Depths of 2m, 4m, 6m and 8m were compared. The comparisons, as shown in Figure 12, consider total heating and cooling loads as well as peak and average zone temperatures. In order to see the full effect of zone depth, internal temperatures were calculated under free-running conditions with the HVAC switched off and no temperature control. Peak and average temperatures were derived from the standard operational period of the building (8:00am to 6:00pm, Mon-Fri).

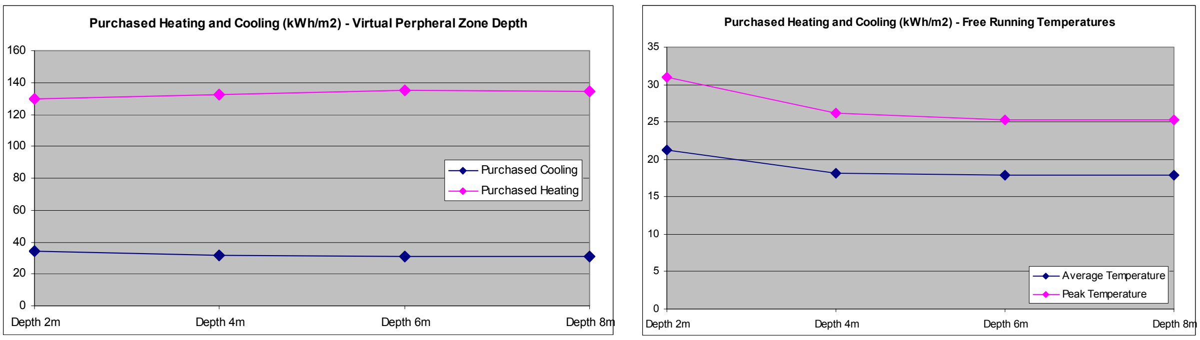


Figure 12. The effect of peripheral zone depth on total annual heating and cooling loads per square metre floor area as well as free running internal zone air temperatures.

Due to increased internal temperatures, the graphs show that small 'virtual' perimeter zones tend to underestimate heating requirements and overestimate cooling. Whilst the percentage overestimation effect on cooling is greater than the underestimation of heating, the demand for cooling is much less so the overall loads vary by approximately 2%.

Findings from the solar study

The results of this particular analysis are specific to a particular office building within the UK. However, it does illustrate the application of the analysis method and the types of results that can be derived from its application. Of more importance are the tabulated results from an analysis of a wide range of buildings and climate types, which is the next step in this study.

To summarise the results for this building, the relative effect of variations in each parameter is shown in Table 3 as a percentage of predicted overall kWh/m^2 load for the year (shown in bold). Table 4 shows the minimum and maximum values used for this comparison.

As comparisons were based on the sum of total annual heating and cooling loads, the values in the table represent variations in the combined heating and cooling load. A negative value is therefore a reduction in overall load whilst a positive represents an increase.

Table 3. Percentage variation of predicted total annual load from predicted 'average' load with variation of individual solar parameters

Parameter varied:	SHGC	Horizontal External Shading Depth	Dynamic External Shading	Internal Shading Convection	Internal Exposed Thermal Mass	'Virtual' Perimeter Zone Depth
Annual	**166.45**	**166.45**	**166.45**	**166.45**	**166.45**	**166.45**
Min	-0.7%	0.0%	0.0%	-2.1%	3.1%	4.0%
Max	1.1%	1.4%	-1.1%	3.2%	-2.6%	-0.9%

Table 4. A summary of the maximum and minimum values for parameters used in Table 3.

Value	Min	Max
SHGC	0.1	0.9
Horizontal External Shading Depth	200mm	2000mm
Dynamic External Shading	100W/m2	600W/m2
Internal Shading Convection	0.10	0.87
Internal Exposed Thermal Mass	No Surfaces	All Surfaces
'Virtual' Perimeter Zone Depth	2m	8m

Overall Conclusions

The paper has shown how loads on the heating and cooling systems in a UK Office building can be broken down by modelling into the main components making up that load, and what the relative importance of these components were in the building studied. The methodology used for this assessment will be applied across a range of European locations and building types as part of the AuditAC project.

The solar study has shown that it is possible to determine the relative influence of a wide range of solar parameters on total heating and cooling requirements. Once applied to many buildings, this will enable the derivation of trends that will enable a qualitative assessment of the physical characteristics that are most likely to affect solar overheating of a range of buildings in various climates. The assessment of characteristics will inform auditors working under Article 9 of the European Directive on the Energy Performance of Buildings as to the most appropriate preliminary advice to provide to minimise solar overheating in the specific building they are working on.

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building performance congress

Reducing cooling energy demand in service buildings

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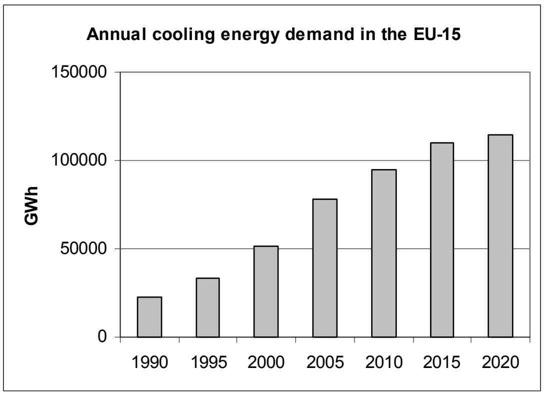
Abstract
Recent EU studies predict a four-fold growth of cooling energy demand in Europe between 1990 and 2020. In most of the cases, this increase can be connected to three factors: not appropriately constructed buildings, growing internal heat loads and an inappropriate translation of people's comfort needs into temperature, moisture and air quality requirements. Setting these conditions right can reduce the unnecessary part of the cooling demand. Most of the remaining heat can be removed by passive cooling technologies.

The international project KeepCool collects the knowledge available about summer comfort without wasting energy and makes it available for building owners, planners, tenants, facility management companies and other stakeholders. Three things are important for the market transformation: First, summer comfort needs to be considered at the earliest possible stage in the design of buildings. Second, the building owner takes a crucial role, being in stage to demand energy efficient solutions from designers, and energy efficiency in operation and maintenance from tenants or professional facility managers. And third, the diversity of these target groups and their needs calls for a multifaceted and flexible approach to market change. KeepCool's approach encompasses a tool-kit, web and media appearance, but also reference groups of suppliers, events with the target groups, concrete advice and pilot projects. These activities should induce a development away from energy intensive cooling techniques towards sustainable approaches to provide summer comfort, and thus prevent a further increase of energy consumption for cooling in Europe.

Energy Consumption for Cooling is increasing rapidly
Around 40% of the overall energy requirements of member states of the European Union is accounted for by the building sector. In the non-residential sector, air conditioning makes up for a significant part of the energy requirements. The IEA Future Building Forum forecasts that one of the fastest growing sources of new energy demand is cooling (International Energy Agency, 2004). The studies EECCAC and EERAC predict for Europe a four-fold growth in air-conditioned space between 1990 and 2020 (Adnot et al, 1999; 2003, see also Figure 1).



Forecast by the project EECCAC. The numbers stem from Adnot et al, 2003, p. 21.
Figure 1: Annual cooling energy demand in the European Union.

This increase can be related to three main developments in the commercial building sector (Varga, 2005):

1. **Bad building design:** Air conditioning makes possible to run buildings with insufficient solar protection and insufficient thermal mass. In fact, many service buildings are being built without considering these most elementary rules of construction, and leaving comfort issues solely to the HVAC equipment.
2. **Increasing internal heat loads:** The boom in the use of electric office equipment caused a strong increase in internal heat loads. The electric energy feeding computers, faxes, photocopiers, electric lighting etc. ends up as waste heat in the room. This amount of thermal energy can be so large that in some cases the core parts of office buildings need to be cooled even in wintertime.
3. **Comfort needs translated to inappropriate thermal requirements:** In air-conditioned buildings, temperature is often kept within a very narrow range around a fixed level, independent from external conditions. This produces often large temperature differences between indoor and outdoor, felt as uncomfortable from a number of people.

In addition, most service buildings are situated in urban areas, and are subject to the so-called “urban heat island effect”. Urban climates are generally warmer and less windy than rural areas. In summer, the urban heat island results in an increased energy demand for cooling. Air conditioning systems are less efficient when operating under large temperature differences and need additional capacity. This way, hot periods can lead to a dramatic rise in the demand for air conditioning, and also increase the peak electricity demand.

Sustainable summer comfort to reduce cooling energy demand

Taking into account the losses that take place both in electricity generation and in the chain from the power plant to the final useful service requiring electricity, energy saved at the end-user level has a larger effect on reducing demand of energy resources than any other measure. This is also true for investments in the energy chain and for the environmental impact of the entire energy system. Therefore our logical path will necessarily start from analysing the means to reduce energy demand at the user level, in this case in the building.

Our experience with energy issues in buildings is twofold: first, one can not be early enough in integrating energy aspects into the planning process. The most important steps to avoid cooling need already take place in the design phase of buildings. Second, for both new and existing buildings, the building owners are the driving force in the investment process. If they are aware about their possibilities, building owners can communicate energy efficiency concerns towards planners, but also can include them in the tenants´ contracts.

Therefore, our approach is to sensitise building owners to an issue that we call sustainable summer comfort. Sustainable summer comfort can be defined as achieving good summer comfort conditions with no or limited use of conventional energy (fossil and nuclear) and through the use of environmentally non-harmful materials.

Instead of setting maximum energy input or prescribing certain technologies to be used, we propose a logical sequence of steps that should be considered when designing, constructing and operating a building. This approach has the advantage of leaving ample freedom to designers while supporting them in adapting the building to the local situation (climate, culture, locally available materials). In addition, this approach leaves open the possibility to find and implement even better strategies and technologies in the future. Not all steps and actions will be available in a specific situation to the owner/designer (e.g. urban planning is outside their competences, but in certain cases the design of a relatively large area with a number of buildings and open spaces might be possible etc.), but our suggestion is to follow this path and closely analyse what are the possibilities for action in a given situation for each step, stating explicitly why the implementation of a specific step may not be possible in a given situation before proceeding to the next step.

Box 1: 10 steps to achieve sustainable summer comfort

1. Define explicitly the thermal comfort objectives, using the Adaptive Comfort model wherever possible.
2. Intervene on the site layout and features which can affect summer comfort
3. Control and reduce heat gains at the external surface of the envelope
4. Control and modulate heat transfer through the building envelope
5. Reduce internal gains
6. Allow for local and individual adaptation
7. Use passive means to remove energy from the building
8. Use active solar assisted cooling plants
9. Use high efficiency active conventional cooling plants
10. Train building managers and occupants on how to use, monitor performances and adequately operate and maintain the building.

The ten steps for achieving sustainable summer comfort in detail

1. Define explicitly the thermal comfort objectives, using the Adaptive Comfort model wherever possible.

In most present buildings and building regulations, thermal comfort objectives are stated on the basis of the analytic model of Fanger (1970), that proposes to predict the comfort vote of the occupants of a building in function of the indoor air temperature, surface temperatures, humidity, air velocity, their assumed activities and clothing. The idea behind this comfort model is the assumption that people feel comfortable at a temperature level where there is no heat exchange between them an the environment (steady-state). The surveys for constructing a correlation between above variables and the comfort vote were performed in climate chamber experiments.

At the same time, Nicol and Humphreys (1972) proposed the Adaptive Comfort model that states that people in real buildings, naturally ventilated, tend to adapt their comfort requirements to the prevailing outside temperatures. This model takes into account that people in real life situations are not functioning at constant conditions; instead, they vary their activities, metabolic rate and clothing according to the climate and its variations. Thus, the optimum indoor temperature (that is the one at which occupants will report comfort) varies with the external outside temperature; in particular, it has a correlation with the average external temperature in the last few days.

Standard ISO 7730 is based on the steady-state Fanger model of human physiology and since it is often used assuming ‘typical values’ of clothing and activity, it has a tendency to specify a narrow band of ‘comfortable’ room temperatures in most applications. In recent years, some international standards (e.g. ASHRAE 55 2004 and the draft PrEN 15251) have considered adaptive comfort models based on comfort surveys in the field. These standards have replaced existing temperature standards with ‘adaptive’ standards for indoor temperature in naturally ventilated buildings.

The adaptive comfort model has been refined over the years, and tested by various field studies (Humphreys, 1975; 1978; 1979; Nicol, 1993; de Dear, 1998; Nicol & McCartney, 2001). McCartney and Nicol (2002) even presented a control algorithm for air-conditioned buildings that utilises the adaptive comfort model. Four conclusions can be drawn from these field studies (McCartney and Nicol, 2002):

1. People in different countries and different buildings really do adapt their comfort requirements to the prevailing outside conditions.
2. The Adaptive Comfort Algorithm backed up by the SCATS project’s field data provides a better prediction of the comfort temperature than the Predicted Mean Vote (PMV) of the Fanger Model
3. Buildings using the Adaptive Comfort Algorithm instead of a constant indoor temperature provide equal or better satisfaction levels while using considerably less energy (up to 30%).
4. Additionally, the adaptive model allows more buildings to be naturally cooled than the narrow requirements that result from the steady-state model of Fanger, as generally used.

In order to move building design closer to real-life comfort requirements and at the same time to reduce cooling energy demand, we propose this model to be adopted in building regulations and construction norms wherever appropriate. Further studies are underway to confirm its applicability also in conditioned buildings.

2. Intervene on the site layout and features which can affect summer comfort

A compact urban layout may be useful to reduce irradiation on external surfaces in hot dry climates, while an openly spaced layout might be required in humid areas to increase ventilation possibilities; the presence of vegetation and surface water, the solar absorbivity of urban surfaces (streets, parking spaces,…) can strongly influence surface and air temperatures in open spaces surrounding the buildings.

3. Control and reduce heat gains at the external surface of the envelope

Heat enters through the external surface or boundary of the building because of the absorption of solar radiation and of the difference between outside air temperature and inside air temperature.
A high reduction of the amount of heat going through the external surface (or boundary) can be achieved by means of solar protections designed to shade windows when required (and possibly also walls and roofs), by surface finishings with adequate values of reflectivity and emissivity, and by means of limiting air exchanges when outside air is at higher temperature than inside air.

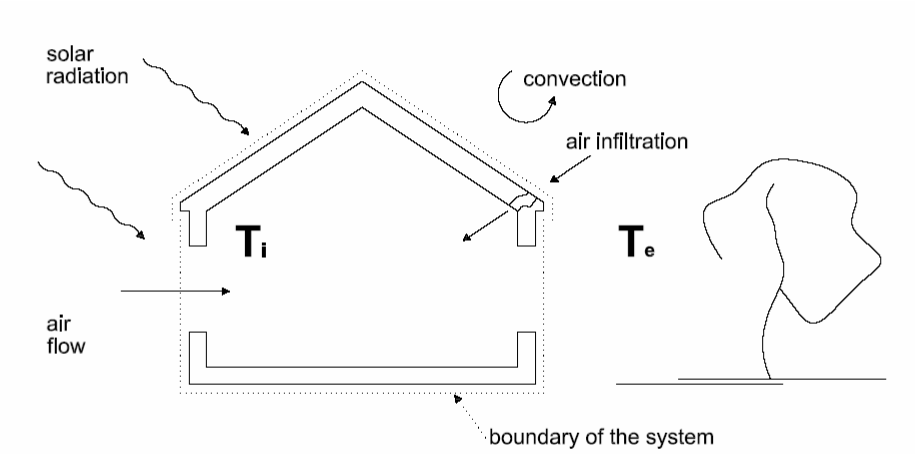


Figure 2: Thermal energy flows though the boundary separating the building and its environment because of absorption of solar radiation, convection exchanges with the atmosphere, air infiltration and air flows through cracks and openings.

4. Control and modulate heat transfer through the building envelope

Once heat has passed through the external surface or boundary, its movement to the interior (via heat conduction and convection) should be limited by appropriate use of insulating materials and the time lag by which it gets to the interior should be controlled by appropriate size and position of thermal mass.

5. Reduce internal gains

Internal gains should be reduced by using efficient lighting sources and systems (notably the most efficient one, daylight); by direct venting of spot heat sources; by using efficient appliances and equipment, by increasing the efficiency and reducing the size of HVAC equipment where installed.

6. Allow for local and individual adaptation

Allow for local and individual adaptation via a flexible dressing code, low thermal insulation furniture, use of ceiling fans, and flexible working hours during high temperature periods up to a few days of “heat wave holidays”.

7. Use passive means to remove energy from the building
Once having reduced external and internal gains and having allowed means to individually adapt, if the desired comfort objectives are still not met, use passive means to remove energy from the building and/or increase comfort (comfort daytime ventilation, night ventilation, use of the ground as a heat sink – directly or via a heat transfer fluid –, radiation of energy to the night sky, direct or indirect evaporative cooling).
An important issue here is the definition of a passive measure. We adopt the definition given by Givoni (1991, p. 177):

> "the term passive… does not exclude the use of a fan or a pump when their application might enhance the performance. This term emphasizes the utilization of natural cooling sources, or heat sinks, for the rejection of heat from the building and, if some power is needed to operate the system, that the heat transfer system is low cost and simple and that the ratio of power consumption to the resulting cooling energy is rather low …"

8. Use active solar assisted cooling plants
If passive means are not sufficient to achieve the thermal comfort conditions assumed as an objective at step number 1 for a sufficient fraction of time, then remove the excess thermal energy from the building via active solar assisted cooling (e.g. absorption and adsorption cycles driven by heat from solar collectors).

9. Use high efficiency active conventional cooling plants
If, and only if, steps 1-8 are still not sufficient to achieve the desired thermal conditions, use conventional active cooling plants with high efficiency. Design this active system always in combination with steps 1-8 so that they are only responsible to remove peak loads in extreme hot times or in special parts of the building, and the major part of the summer comfort is provided by the previous steps. In case of existing buildings with existing HVAC systems, try to use steps 1-8 to reduce cooling loads and improve the efficiency of the existing plant using the same approach, i.e. starting from as close as possible to demand. This means intervening first at the level of the diffusion of cold air to the internal environment, going then upward to the distribution system (air or water), reducing pressure drops in the ducts (straight ducts layout, choice of low friction elements) and leakages, increasing the efficiency of heat exchangers, shading the condensers from the sun, using efficient fans, pumps and motors with variable speed regulation. Intervening in these ways to reduce losses in the chain allows finally for the use of a smaller size and more efficient vapour compression cycle.

10. Train building managers and occupants on how to use, monitor performances and adequately operate and maintain the building
Having followed the previous steps, the entire building (rather than the active plants) is the means for reaching comfort conditions. Clear and exhaustive manuals should be prepared, and an initial training provided, to allow the management staff and the occupants of the building to know how to rationally operate and control the building and its systems/plants when present.
For new buildings, a monitoring plan should be prepared to asses whether the performance (comfort, consumption) of the building matches the design objectives and the persistence of good performance over time.
A maintenance plan should be followed (ordinary planned maintenance and extraordinary maintenance when decay of performance is detected).

KeepCool: An international project that promotes sustainable summer comfort

Throughout Europe, several projects are running on energy efficiency in buildings. One of them is the EIE-project KeepCool (Contract No. EIE/04/179/SO7.39459). The overall goal of the project is to facilitate market penetration of sustainable cooling approaches and technologies in the participating countries, and implement activities that prevent a further increase of cooling demand in Europe. KeepCool addresses both newly constructed and existing service buildings (both public and private sector). Since the buildings owners are the driving force in the investment process, the project focuses on convincing building owners on the benefits of sustainable cooling solutions through marketing and dissemination of already existing technologies, knowledge and tools. In addition, the project aims at supporting the cooperation between suppliers and ensuring the link to policy instruments, that might support sustainable summer comfort.

Nine partners from eight European countries form the core team of the project (see Table 1). This distribution ensures that both the two biggest markets in hot regions (Spain and Italy) and the fast developing markets in moderate and cold regions can be reached by the project.

Table 1: The KeepCool project partners

Country	Organisation
Austria	Austrian Energy Agency, Coordinator
Austria	Arbeitsgemeinschaft Erneuerbare Energie (AEE INTEC)
Germany	IZES gGmbH
United Kingdom	National Industrial Fuel Efficiency Service Limited (NIFES)
Lithuania	Lithuanian Energy Institute
Sweden	Swedish Energy Agency
Italy	Politecnico di Milano, Dipartimento di Energetica (eERG)
Spain	Sociedad para el desarrollo energético de Andalucía (SODEAN)
Portugal	Centro de Estudos em Economia da Energia, dos Transportes e do Ambiente (CEEETA)

Targeted marketing needed to remove incentives from wasting cooling energy

Market situation in Europe

Most of the solutions we are proposing had been common sense in ancient architecture. For thousands of years, the only way to provide summer comfort was to design a building that keeps heat out and has enough thermal mass to level out daily temperature changes. Architecture in hot regions especially considered summer comfort: light coloured surfaces, shading, appropriate urban design, but also evaporative cooling can be observed for example in Arabic or Greek architecture. With the availability of mechanical air-conditioning (AC), these solutions became marginal in the developed world. This development is compensated by the fast growing rate of AC systems, as presented in the introduction.

Nevertheless, in every participating country we can find good practice examples that can be used as "condensation point" for our marketing activities. Best practice is an approach to convey the energy, economic and comfort gains of a "new" technology without appealing to moral or ecologic instances. On the other hand, energy efficiency in buildings is beginning to play a role again. This is due to the present climate debate, but also to the raising energy prices at the world market. The new Energy Performance in Buildings Directive (EPBD) of the European Union sets targets for the energy efficiency of buildings. Other forthcoming directives, such as the Efficiency Directive, will support political development in the right direction. Both developments can be used to promote sustainable summer comfort: The first, since the exploitation of building envelope and passive approaches prior to using active AC can considerably reduce energy (especially peak energy) consumption of buildings, and with this also decrease the CO_2 emissions connected to it. Second, there is reason to hope that the energy certificates issued following the EPBD will be perceived as certificates of overall quality by market actors and therefore become a market driver for energy efficiency measures.

Target groups

Therefore, the overall goal for KeepCool is to make the concepts of sustainable summer comfort available and known to building owners, tenants and other market actors.

Building owners are the core target group. As investors and decision-makers they greatly influence the engineers, different consultants and the architects. By setting up requirements for buildings in general and specific targets on cooling solutions they are able to set the framework for the planning process and thus have a major impact on the market. Building owners also control the planning process. Very often know-how on single elements or components of sustainable solutions is available. There is a need for advice, however, related to the necessity to include these systems into an integral planning process. For complex projects, building owners are increasingly accompanied by procurement specialists, who – additionally to the technical tasks of architects and planner – are responsible for an optimal procurement process.

Building consultants from different areas could form a "expert team" on cooling. The planning process must include collaboration and exchange of information between the consultants (i.e. input data for calculations). Checklists for the building owners to control this process are important.

Tenants represent an essential target group as they can influence both the performance of the building (room temperatures) and the energy performance through rental agreements. Tenants with an environmental policy could ask for buildings with sustainable cooling solutions.

O&M staff needs to be addressed as they are key persons in the actual function of the systems. They need information on how sustainable cooling is operated (maintenance of sun protection, night cooling, but also the maintenance of conventional systems). They are also important as a link to the tenants with information on the system.

The interaction of all these target groups determines design and use of cooling technologies. This interaction is a complex process that varies from object to object. Figure 3 shows a possible (and simplified) scheme.

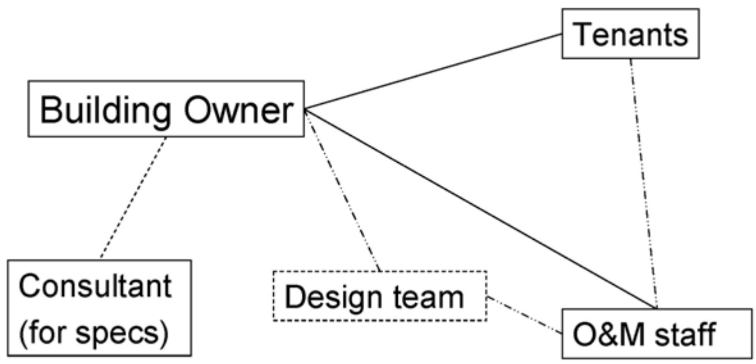


Figure 3: Scheme of the complex interaction among our target groups. There are contractual agreements between the building owner and the tenants, as well as with the O&M staff. These contracts might contain also comfort levels, or operational prescriptions. The building owner probably gets advice from consultants. Communication on technical issues or on explicitly stated comfort objectives would be necessary but seldom takes place between building owners, the design team, the design team and the operation & maintenance (O&M) staff, and between the last and the real occupants.

In order to achieve real change, the marketing activities must go beyond pure dissemination and information transfer. They must include also activities related to "market transformation" by bringing together the relevant market actors and build up a structured supplier/customer dialogue. Where necessary, this includes also activities at the level of public administration decision makers. Furthermore the participating partners focus their activities in the work packages on selected target groups and key actors.

Multiple marketing activities to reach a diverse target group
Since we want to reach market change at a complex mixture of target groups, each of those with probably different needs and expectations, our marketing activities must be diverse and flexible at the same time. The KeepCool project contains a wide variety of marketing measures:

- Development of a toolkit accessible by building owners
- Reference groups of suppliers
- Concrete advice to building owners and planners
- Pilot projects that are testing our approach
- National and international events, media coverage
- Website

This is the “marketing toolbox” that our participants can choose from. Depending on the individual situation in every participating country, different measures will be performed at different places and times. For example, in Austria we can take advantage of an already successful programme on energy efficiency refurbishment of private service buildings, that is present at this conference, too (Grim, in prep.). Therefore, marketing activities in Austria concentrate on concrete advice in already existing projects and possibly set up one or two pilot projects that can be followed by others. In Sweden, marketing uses the strength of professional associations and uses the approach of reference groups. In Italy, which is responsible for 25% of the European AC market (Adnot et al., 2003), climate conditions in certain areas make challenging the realisation of passive buildings. Here, our marketing concentrates on the education of a new generation of architects and engineers who are aware of the potentialities of envelope and passive technologies to reduce the cooling loads and improve comfort. In the following, we detail briefly the main marketing instruments used by KeepCool.

Toolkits for building owners, planners, tenants and O&M team
In case we can motivate building owners, planners etc. to employ sustainable summer comfort practices, we need to be able to provide them with useful and ready-to-apply information. In case that we are able to initiate the development we want to, we also must keep this information available after the project will be finished.

Within KeepCool, available technologies and solutions for each of the above described ten steps have been compiled and summarised. In addition, the legal situation of every participating country concerning summer comfort has been investigated, together with a rough analysis of the European market. Best Practise examples and lists of experts and suppliers of the above technologies were compiled, together with tools for implementing those technologies in buildings design and for assessing their life-cycle costs. All this information has been processed into four web-based tool-kits for building owners, cooling experts / building consultants, tenants, and O&M or facility management (FM) companies. He different target groups are addressed through different toolkits. The first addresses the building owner as a “landlord” and decision maker for the cooling solution, providing definitions and arguments to discuss with the design team. The second toolkit is to be used by an expert – either the building owner or a building consultant in case there Is no in-house expertise. This toolkit provides detailed information for the steps included in the building owner’s checklist. The toolkit for communicating with tenants should support the dialogue regarding thermal comfort, and regarding the use the alternative solutions. The last toolkit should provide instructions to the O&M or FM companies so that the comfort is delivered as foreseen.

The toolkit will be the “written heritage” of the project. Publishing it at the World Wide Web (WWW). has two big advantages: First, it can be made accessible for free by anybody, thus lowering the entrance barriers. Second, it remains flexible for later amendments as technologies or markets develop. On the other hand, much information material is published and gets immediately lost at the WWW, without having any effect on the people it should inform. Therefore, the toolkit must always be accompanied by appropriate marketing measures.

Involvement of key actors - creation and animation of national reference groups
Key actors are here defined as actors supplying equipment for sustainable cooling solutions (suppliers of sun protection, efficient equipment etc.). A reference group will be set up with

participants from all key actors. The objective is to trigger the key actors to offer solutions to building owners. Meetings with this reference group will be held with the objective to:

- Show to the key actors the potential market for sustainable cooling;
- Give the actors a meeting point to start cooperation;
- Prepare national seminars where both the project participants and the key actors will be engaged;
- “Package” solutions from key actors. “Packaging” solutions means that the key actors would offer solutions as one body to the building owner. The building owner then only has one contact which saves time.
- Show key actors environmental and economical benefits with sustainable cooling.

Depending on the situation in each country key actors can be either trade organisations or specific companies.

Concrete advice to building owners
This contains concrete advice in projects. The focus of advice will be on support to the building owner, who sets the requirements for the project. Therefore advice relates less to technical advice but rather advice concerning setting targets and verifying goals. Face to face meetings with building owners (including partly also other target groups) is the objective of this task. It is also important to guide the target group to the right companies and specific persons experienced in this field. A telephone contact (hot-line) will be available in each country. The project team will develop specific tools (e.g. checklists) that give an efficient guideline to face-to-face-meetings.

Pilot projects
Members of the project team will accompany the implementation of sustainable cooling solutions in 3-5 pilot projects. The focus will be an improvement of cooling in existing buildings. The objective of the pilot projects is to give concrete advice in the planning process and on technical issues. The experiences from the pilot projects will give a feed back on the tool kit. An even more important objective is to give advice on how specifications used in the procurement process can verify sustainable solutions and how this is implemented within the building owners organisation, in order to make sustainable cooling solutions a standard.

Events and articles
Interested building owners and even pilot projects do not grow on trees. “Above the line” marketing activities are needed to attract the target group’s interest. For this purpose, seminars, workshops or events at trade fairs can be held, if possible with involvement of key actors. These events/workshops should be as practical and as adjusted to every day work of participants as possible. In some cases even case-studies will be worked out during the workshops.

To start with an even lower level or to increase the effect of such events, sustainable summer comfort can appear in general and/or specialist media. These appearances can take the form of case studies on best practice, reports or announcements of events or even advertisings for certain products or services. The EPBD and its energy certificates can function as eye-catchers to open the minds of the target groups for energy efficiency in buildings.

Websites
Websites are suitable to display information in a widely accessible and understandable way. However, they must be accompanied by other marketing activities. In the case of sustainable summer comfort, all relevant information and findings are published at the project’s website www.keepcool.info, and other marketing channels (articles, events, concrete advice) refer to this website. In particular, the toolkit will be available here. National approaches may enclose other websites. In Germany, for example, KeepCool found entrance to a buildings info line http://www.baunetz.de. In Austria, the main findings will be linked to the national climate program’s website www.ecofacility.klimaaktiv.at.

Conclusions

Following the 10 steps towards sustainable summer comfort means to:

1. consider the building as a whole and its multiple interactions with its environment and

2. exploit envelope/passive measures (e.g. building envelope design, climatic conditions and natural energy sources) to achieve the desired - and explicitly stated - comfort objectives.

This is the contrary of the design process that is often prevailing today. Here, design architects/engineers tend/are forced to delegate the achievement of comfort conditions to HVAC engineers, which in turn cannot intervene in decisions about building envelope, lighting systems, and not even the building layout which affects the placement of mechanical equipment and ducts. In this way, internal comfort is achieved primarily through active measures, i.e. cooling and ventilation based on importing fossil energy into the building. The result of this lack of integration is a large number of buildings which are less pleasant to inhabitate, more costly to build and several times more costly to keep comfortable in summer than they should be.

Through the involvement of building owners, planners, tenants, O&M staffs and consultants and the above mentioned broad marketing campaign KeepCool wants to raise new demand for sustainable solutions, and for buildings that are in line with their occupants´ comfort needs, and use as little energy as possible to keep these comfort needs. Thus, the project wants to contribute to the ongoing discussion on energy efficiency in service buildings.

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building
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Field testing of several CO_2/presence based Demand-Controlled Ventilation techniques within six different tertiary sector buildings

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[2] *Costic*
[3] *CSTB*
[4] *Aldes*
[5] *Anjos*
[6] *Atlantic*

Abstract

Demand-controlled ventilation (DCV) has been proposed and implemented over the past several years as a strategy for increasing energy efficiency by providing outdoor air ventilation rates based on actual occupancy rather than design occupancy. It has largely been documented in the literature through field demonstration projects and computer simulation studies. However, in France and in the majority of European countries, the use of this technique is still quite limited.

Several partially unanswered questions fuel this paradox:

- What is the real impact of DCV on comfort and air quality?
- What are the real energy savings which can be expected?
- How reliable are these systems over the long term and what are the real operational difficulties related to these systems?

This study provides additional field test data to help bring answers to these questions. The study was undertaken by three manufacturers of DCV systems (Anjos, Atlantic and Aldes), three HVAC research labs (CSTB, CETIAT and COSTIC) and an energy services company (Elyo). The study was co-financed by the ADEME agency.
Six buildings from various sectors (education, health, justice) which were identified as being adapted to the use of DCV systems were equipped with various DCV technologies and were studied over two 15 day periods (summer and winter).
The trade mark technologies of the three French manufacturers VARIVENT (Atlantic), ALIZE VISION (Anjos) and MDA-Agito (Aldes) were selected. The selected building applications were: a school canteen, a rehabilitation centre consultation room and gymnasium, a university library meeting room, a classroom and a courtroom.

The study quantifies in particular:

- The impact on comfort and indoor air quality both measured and felt by the occupants,
- The net energy savings by comparing them with the real operating conditions in the “before DCV condition”,
- The difficulties with respect to the installation and maintenance under real operating conditions.

The results provide information useful in better targeting the implementation of DCV techniques as a function of the building type and use. The study showed that the interest in terms of comfort and indoor air quality is obvious; however, the real energy savings depend on the pre-existing operating conditions. Ultimately, the profitability and the reliability of DCV systems depend on their appropriation by the building’s energy management personnel.

Introduction
When properly designed and installed, DCV can reduce unnecessary over-ventilation that might result if air intakes are set to provide ventilation for a maximum assumed occupancy, particularly where occupancy is intermittent or variable from design conditions. DCV technology is particularly relevant for buildings with a highly variable occupancy such as conference rooms, offices, theatres which require a forced ventilation system when the rooms are at full capacity and almost no ventilation 80 to 90% of the time. The first inexpensive CO_2 sensors designed specifically for ventilation control in HVAC applications appeared on the market over 2 decades ago. Long term drift of the sensors was a problem at the beginning and required calibration annually or more frequently. The need for frequent calibration provided an unexpected added cost for HVAC related applications and discouraged their widespread use. New generation sensors are now equipped with auto calibration algorithms to correct for changes in the optics of the sensor or particle build-up over time which may result in sensor drift. Some sensors calibrate themselves on a nightly basis when the space is unoccupied and inside levels drop to baseline outside levels. Good long term stability is now achievable with new generation sensors.

Numerous scientific papers detail the technical aspects of DCV and the potential energy savings which are estimated at up to 80%. In most cases, the system payback is estimated to be as little as a few months to 2 years. In spite of these results, very few systems have been installed in France in new buildings and almost none in existing buildings.

Project Objectives
Thus the objectives of this study were to determine for several tertiary sector buildings which DCV are best suited to the each particular application and what are the main difficulties with respect to the installation and maintenance of these systems under real operating conditions. In addition to the aforementioned objectives, this study also presented the opportunity to evaluate SIREN (a simulation model developed by the CSTB) in modeling new DCV systems and to provide feedback on the technical specifications used by the CSTB in adjudicating the use of new DCV systems in France.

Presentation of the different partners
The partners in the project team where:

- Elyo Cylergie (Elyo’s Research and Development Center). Elyo is an Energy Efficiency Services Company, subsidiary of Suez Energy Services.
- Centre Technique des Industries Aérauliques et Thermiques (CETIAT), the French technical centre of ventilation systems manufacturers
- Comité Scientifique et Technique des Industries Climatiques (COSTIC) research laboratory
- Centre Scientifique et Technique du Bâtiment (CSTB) research laboratory
- Aldes (Demand controlled ventilation system supplier)
- Anjos (Demand controlled ventilation system supplier)
- Atlantic (Demand controlled ventilation system supplier)

Description of the DCV systems used in each test site
Two types of DCV systems where used in this study: CO_2 based DCV and presence based DCV. As a general rule, optical motion sensors (which detect either presence or activity) are used in small to medium volume rooms (less than $60m^2$ / $170m^3$) and CO_2 based systems are used in large volume rooms (greater than $60m^2$). The building applications where these different techniques were used are indicated in Table 1.

CO_2 based DCV
The “VARIVENT” system from Atlantic, the system put in place by Anjos, and the system put in place by the COSTIC were all based on a CO_2 measurement using Non-Dispersive Infrared Detection (NDIR) CO_2 sensors.

The basis for using CO_2 for ventilation control is established in well-quantified principles of human physiology. People exhale predictable quantities of CO_2 in proportion to their degree of physical activity. Because CO_2 is so consistent and predictable, it can be used as a very good indicator of general occupancy trends. Sensors based on the principal of NDIR are used to detect a net increase or decrease of light that occurs at the wavelength where CO_2 absorption takes place, where light intensity is correlated to CO_2 concentrations. Ambient air is allowed to diffuse into a sample chamber that contains a light source at one end and a light detector at the other. A selective optical filter is placed over the light detector to only admit light at the specific wavelength where CO_2 is known to absorb light.

Presence based DCV
The "MDA-Agito" system from Aldes, which was also used by Elyo and the "ALIZE VISION" system from Anjos use optical motion sensors to measure variations in occupancy.

Optical motion sensors produce an electric signal each time a motion of more than 30° is detected and thus estimates the relative variation in occupancy with respect to the number of movements detected within a fixed time period.

Methodology used to evaluate changes in IAQ, comfort and energy savings

The following information was collected from each site during the two 15 day test periods (winter and summer): air flow rates, fan motor voltage, acoustic measurements, occupancy, user satisfaction surveys as well as both indoor and outdoor: temperature, relative humidity and CO_2 concentration measurements. Care was taken to ensure that windows and doors were maintained closed during the measurement periods. During a period of 4 days, the actual occupancy was measured by a person who stayed at the entrance of each room during regular business hours and counted the number of people entering and leaving the rooms. These data were completed or confirmed by way of log books where possible. A user survey was completed by the occupants who were asked to evaluate their perceived comfort and the IAQ upon entering the room and upon leaving the room in terms of odour, noise and sensations of being too hot or cold.

Results

Thermal and Electrical Energy Savings
As indicated previously, optical motion sensors are used in rooms with medium to small surface areas (surfaces and volumes below 60 m^2 and 170 m^3). CO_2 sensors are used in larger scale rooms with surfaces greater than 60 m^2.

However, two rooms with very similar geometries were equipped with different DCV technologies. The class room was equipped with an optical motion sensor and the school canteen was equipped with a CO_2 sensor. Irrespective of the DCV technique used, the results were spectacular with thermal energy savings in excess of 50% in all sites tested.

The formula used in all cases to determine the thermal heat losses by ventilation was the following:

$$THL = 0.34(\beta Qv + aQs)\Delta T \qquad \text{avec} \quad \Delta T = Ti - Te$$

THL: Thermal Heat Losses by way of ventilation (W)
0.34: heat capacity of air ($Wh/m^3 °C$)
a: coefficient = 1.8 for mechanical ventilation systems
β: coefficient = 1 for mechanical ventilation systems
Qv: Ventilation flow rate
Qs: Additional flow rate due to wind infiltration (m^3/h). Taken as 0, as the buildings were not located in particularly windy areas and we did not have information concerning the permeability of the building envelopes.
Ti: indoor temperature (°C)

Te: outdoor temperature (°C)
The formula was thus simplified to: THL (W) = 0.34 Qv (Ti – Te)
The energy savings were calculated by comparing thermal heat losses by ventilation with DCV system with what they would have been without DCV system (i.e. with a constant ventilation flow rate).

Table 1: Summary of results

	Building / Room	**Surface / Volume**	**DCV system**	**Set points**	**Nominal / Actual number of occupants (% occupancy)**	**Thermal energy savings[1] (%)**	**Electrical energy savings[2] (%)**
New Buildings	School / Classroom	60 m^2 / 167 m^3	Aldes MDA-Agito Optical motion sensor acting on the network distribution	Fan speed variation as a function of presence (measurement every 10 min)	25 / 15 (60% occupancy)	84% (W)[3]	N/A
New Buildings	Rehabilitation center / Gym	90 m^2 / 360 m^3	Anjos NDIR CO_2 sensor acting on the fan voltage	Proportional 750 – 1000 ppm 100 m^3/h<750 ppm 500 m^3/h>1000ppm	20 / 10 (50% occupancy)	51% (W) 51% (S)	45% (W) 59% (S)
New Buildings	Rehabilitation center / Consultation room	10-20 m^2 / 25-50 m^3	Anjos ALIZE VISION Optical motion sensor acting on the extraction register	min to max airflow (7.5 m^3/h to 50 m^3/h) re-set every 30 minutes	2 / 2 (100% occupancy)	50% (W) 64% (S)	N/A (W) N/A (S)
New Buildings	School / Canteen	60 m^2 / 150 m^3	Atlantic VARIVENT NDIR CO_2 sensor acting on the fan voltage	Proportional 750 - 975 ppm 220 m^3/h<750 ppm 935 m^3/h>975 ppm	50 / 40 (80% occupancy)	77% (W) N/A (S)	65% (W) 68% (S)
Existing Buildings	University library / Meeting room	32 m^2 / 90 m^3	Aldes MDA-Agito Optical motion sensor acting on the network distribution	Fan speed variation as a function of presence (measurement every 10 min)	25 / 1-2 (5% occupancy)	87% (W)[4]	23% (W)
Existing Buildings	Superior Court / Courtroom	225 m^2 / 1843 m^3	COSTIC NDIR CO_2 sensor acting on the air intake	Proportional 650 - 1700 ppm <650 ppm 20% open >1700ppm 100% open	150 / 30-40 (30% occupancy)	63% (W) 65% (S)	N/A (W)

[1]: the energy savings are presented based on an estimated indoor temperature set point of 20°C and account only for the reduction in heat losses through the ventilation system. It should be noted however, that the energy savings presented on a percentage basis are more or less the same regardless of the indoor temperature set point being considered.
[2]: the electrical energy savings are based only on the consumption related to the fans. The consumption related to the sensors/ regulators was not taken into consideration in this study. As an indication of the potential impact of a 3W sensor, the annual electrical energy consumption would be approximately 27 kWh.
[3]: (W) winter, (S) summer
[4]: It should be noted that the % occupancy is valid during the hours when the building is open to the public. In some instances the original building ventilation system was being operated 24 hours/day and therefore the energy savings with the new DCV were even more significant than the base case.

Thermal and Hygrometric Comfort

In addition to the significant energy savings obtained in each field test site, indoor thermal and hygrometric comfort was maintained: throughout the measurement periods no significant user complaints were reported.

The following figure presents the results from the Rehabilitation Centre Gymnasium winter test period, in terms of indoor and outdoor temperature and relative humidity. The relative humidity oscillated between 75 and 90% outdoors and between 20 and 30% indoors, therefore the rate of air renewal was sufficient to eliminate the humidity emitted by the occupants during their sport activity. The room temperature was estimated to be on average 20°C +/- 1.5°C.

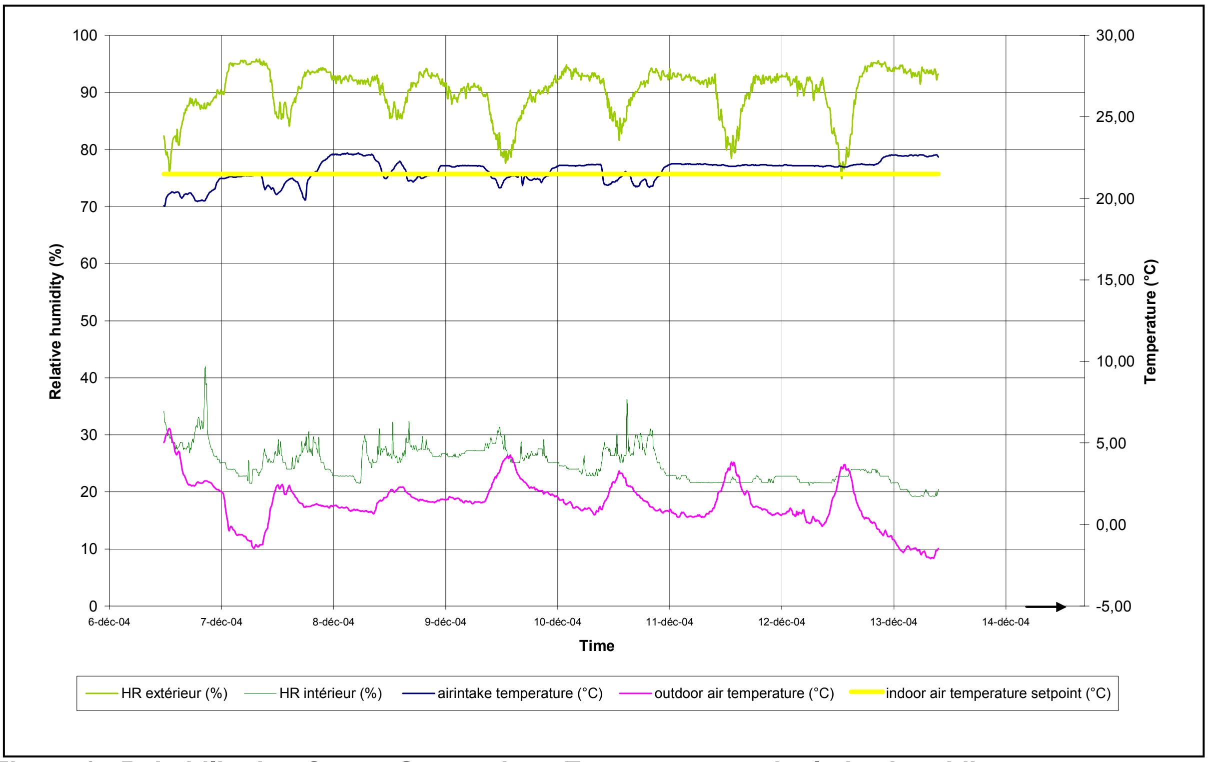

Figure 1: Rehabilitation Centre Gymnasium: Temperature and relative humidity measurements

Indoor Air Quality

The indoor air quality, evaluated as a function of the indoor CO_2 concentration, was also maintained. Levels above 1200 ppm were not reported throughout the field testing both during summer and winter test periods.

The following figure presents the results from the School Canteen during the winter test period in terms of indoor and outdoor CO_2 concentrations and extraction and supply air flow rates during a typical school day. Canteen personnel are present between the hours of 10am and 3pm. The lunch is served from 11:40am to 1:20pm. The two CO_2 peaks correspond to the children entering and leaving the canteen.

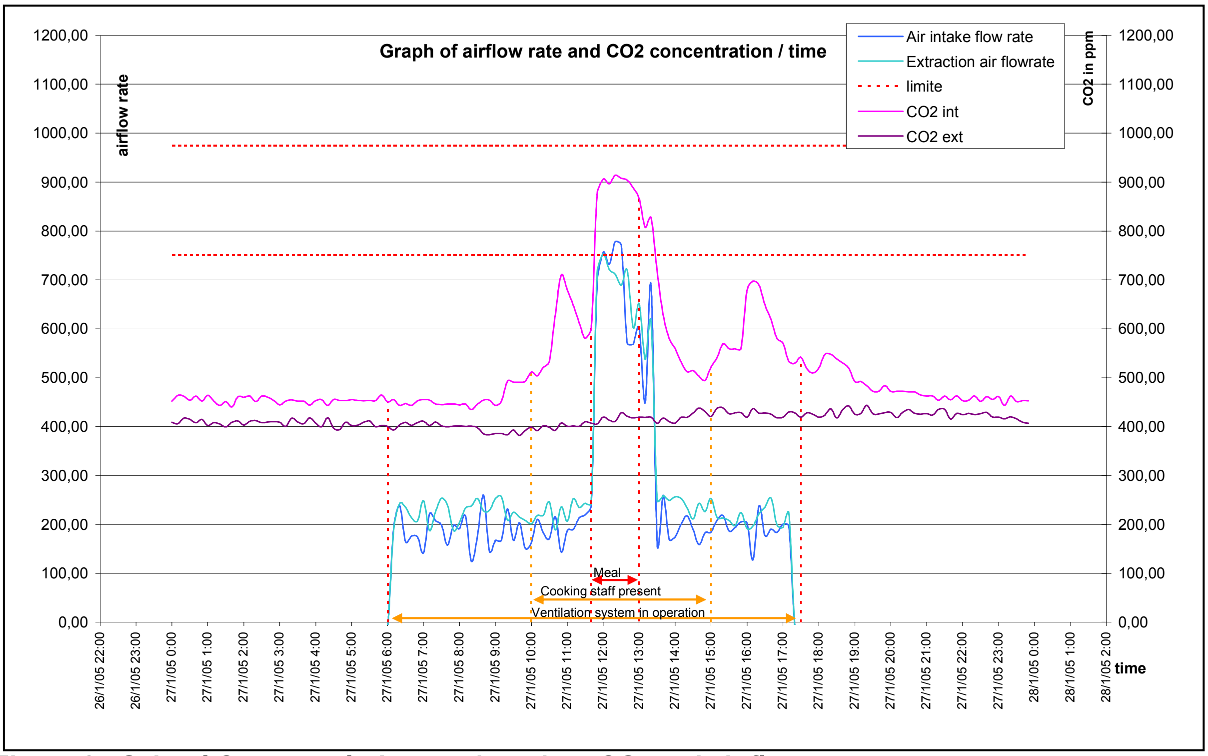

Figure 2: School Canteen: Indoor and outdoor CO_2 and air flow rate measurements

Occupancy

Throughout the field tests, the actual occupancy in each building was well below the design occupancy. The low occupancy rates which were identified confirm the interest in demand controlled ventilation systems for these types of buildings.

The following figure presents the results from the Rehabilitation Centre Gymnasium during the winter test period in terms of occupancy, supply and extraction air flow rates, and indoor and outdoor CO_2 and relative humidity measurements. The results from a typical day show that the room is not used to its full design occupancy (20 people) and that the majority of the time the occupancy is actually in the range of 5 to 10 people.

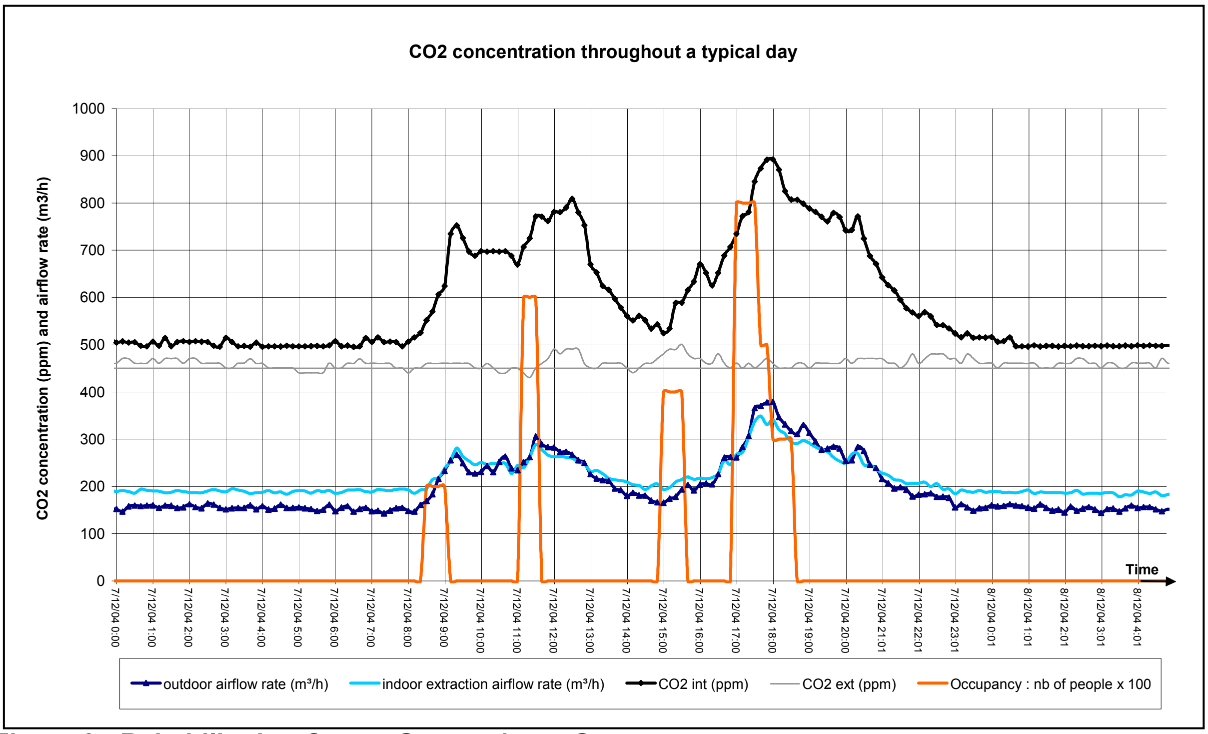

Figure 3: Rehabilitation Centre Gymnasium: Occupancy measurements

User satisfaction surveys

A survey was completed by the users who were asked to evaluate their perceived comfort and the IAQ upon entering the room and upon leaving the room in terms of odour, noise and sensations of being too hot or cold. Throughout the different sites tested, 118 user surveys were completed. Of those surveyed, in terms of perceived IAQ and comfort, 89% reported it as being good, 6% reported it as being average and 5% reported it as being poor.

Difficulties encountered and observations made during the installation and maintenance of these systems

Air-tightness of CO_2 sensors installed in duct work

During the installation of the system in the courtroom, problems were encountered in terms of the air tightness of the seal between the CO_2 sensor and the ductwork. Precaution should be taken to ensure a proper seal especially when installing CO_2 sensors in ducts. No problems were identified when installing wall mounted CO_2 sensors.

Retrofits in existing buildings

A thorough evaluation of the existing system must be completed before installing DCV systems to ensure that the existing system was installed and is operating as designed. The following steps should be completed:

- Verify the distribution network (sizing, condition of the network, and verification of any air tightness problems),
- Verify the air flow rates and pressure drops at each supply and extraction point, and
- Verify that the servomotors and valves are functioning properly.

Complexity of the control strategy
Setting up the control strategy for DCV systems integrated within existing HVAC systems can be a rather complex task and therefore should be completed and maintained by on-site energy services personnel.

Calibration of sensors
Optical motion sensors do not require any particular maintenance. However, CO_2 sensors must be calibrated periodically. Slight sensor drift was noted on several sites especially after power outages or after having been dismantled and re-installed after several months of being unused.

A complementary study is underway to evaluate the reliability of NDIR CO_2 sensors. Results are expected at the beginning of 2007.

CO_2 stratification
Punctual CO_2 measurements were carried out at different locations in the courtroom.
CO_2 measurements were taken with two different CO_2 sensors. No CO_2 stratification is highlighted.

Modeling with SIREN

Where the actual occupancy patterns were well identified, the results obtained with the SIREN model reflect quite well the actual measurements obtained during field testing.

The following figure presents the simulation and measured results in terms of indoor CO_2 concentrations from the university library meeting room equipped with an MDA-Agito DCV system. The outdoor CO_2 concentration was set arbitrarily at 375 ppm as problems were encountered due to the CO_2 sensor drift. The blue line indicates the results from the simulation.

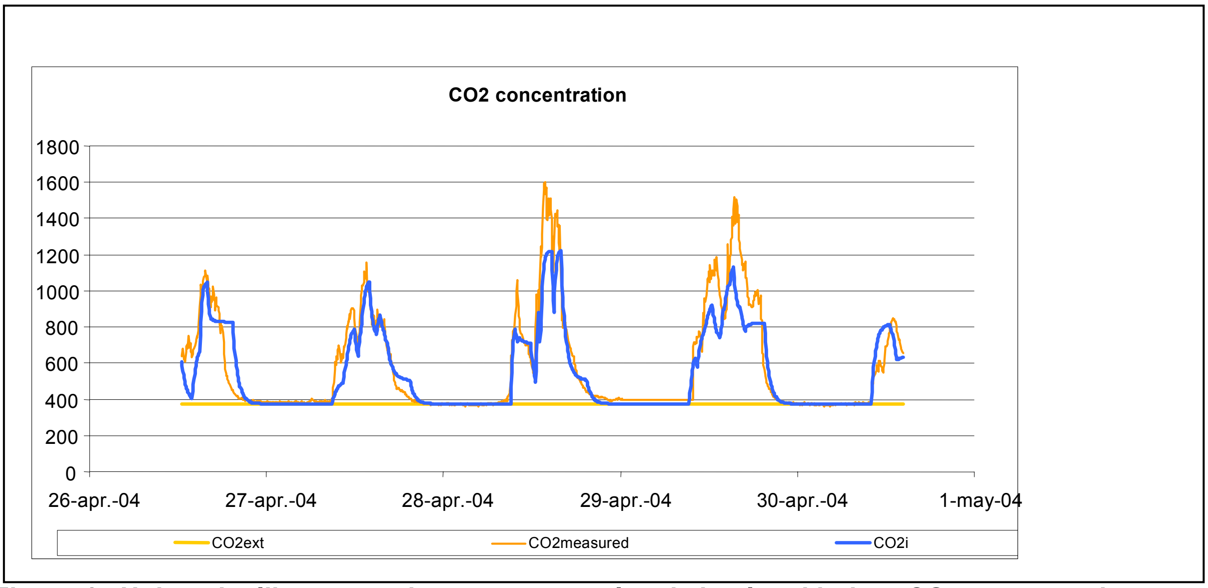

Figure 4: University library meeting room: actual and simulated indoor CO_2 concentrations

Building type and best applicable DCV technique

The following table presents a listing of the best applicable demand controlled ventilation technologies. Many different control strategies exist. The trade off between temperature control and air quality must be attained. In most cases a set point or proportional control strategy will suffice. However, a proportional-integral control strategy is recommended when dealing with a large volume and low occupancy to void problems with a lag in response time.

Duct sensors are best used where a single space or multiple spaces with common occupancy patterns are being ventilated.
Criteria for placement of wall-mounted sensors are similar to those for temperature sensors. Installing in areas near doors, air intakes/exhausts or open windows should be avoided.

Table 2: Summary of building types and best applicable DCV technology

			Recommended DCV Technique		
			Sensors	**Modulation**	**Control Strategy**
Building Type	Human contaminants only (CO_2)	Residential	Relative humidity	Modulation of air inlets /air outlets areas based on humidity	Set point
		Tertiary : known occupancy at known times	Timer	Variable voltage for fan or damper position	Set point
		Tertiary : known occupancy at variable times	NDIR CO_2 or optical motion sensors (surface-mounted)	Variable voltage or frequency (2 speed) for fan, damper or incliner, as needed	Set point (with timer)
		Tertiary : variable occupancy at known times	NDIR CO_2 or optical motion sensors (surface-mounted)	Variable voltage or frequency (2 speed) for fan, damper or incliner, as needed	Proportional
		Tertiary : variable occupancy at variable times	NDIR CO_2 or optical motion sensors (surface-mounted)	Variable voltage or frequency (2 speed) for fan, damper or incliner, as needed	Proportional
		Tertiary : variable occupancy at variable times in a large volume	NDIR CO_2 duct-mounted	Variable frequency for fan	Proportional -Integral

Conclusions

The field testing of several DCV systems, allow the following conclusions to be made:

- Indoor thermal and hygrometric comfort was maintained: throughout the measurement periods no significant complaints from the occupants were reported.
- The indoor air quality, evaluated as a function of the indoor CO_2 concentration, was also maintained. Levels above 1200 ppm were not reported throughout the field testing both during summer and winter test periods.
- Irrespective of the DCV technique used, the results were significant with thermal energy savings in excess of 50% in all sites tested.
- The building's energy management personnel must be implicated in the maintenance of DCV systems to ensure their reliability.

This study was co-financed by the ADEME agency.

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[2] Modulation de débit, Rapport final – A-M Bernard, M. Blazy, CETIAT Report NTV 2000/071, septembre 2000
[3] NTV 2002/111 – Modulation des débits de ventilation, caractérisation des performances – Rapport final – A-M. Bernard, M. Henninot, JG. Villenave, CETIAT, décembre 2002

building
performance
congress

Sizing of solar-desiccant cooling system in the East of France

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Abstract

Solar desiccant cooling hybrid combination is recently proposed as interesting renewable energy system for building cooling. This type of system is made up of a desiccant dehumidification wheel, coupled with a rotary heat exchanger and humidifiers. Regeneration of the wheel is served by means of an air/water heat exchanger, heat solar energy being recuperated from roof solar panels. An insulated water tank constitutes the heat storage where the solar circuit is passed when necessary through a solar/AHU exchanger.

In this paper, we will present a demonstration plant installed in the Center for renewable energies located in Chambery - East of France. It provides cooling for a 70-m^2 training room which major loads come from a glazed facade and from a maximum occupation of 40 people.

The paper explains how to select the components of the system, the sizing procedure and the control strategy design with hydraulic circuit configuration. The solar cooling plant is designed in order to respect the inside comfort conditions without making call to complementary electrical source for regeneration.

The building and system are modeled under Consoclim. Simulation results give the expected values of energy and water consumption, the performance coefficients for the different hydraulic configurations, indoor air temperature and relative humidity all over some representative days. Later publications will deal with experimental results.

Introduction

The use of heat from solar thermal collectors is always represented as an interesting option for thermal driven air conditioning processes. One of such application is the solar assisted cooling system. Desiccant evaporative cooling (DEC) has been largely considered in the last years as an alternative technology to conventional air conditioning systems. Working without the conventional refrigerants and having the ability to supply necessary ventilation with a certain improvement of indoor air quality have enhanced their implementation in commercial buildings. More attention was paid for the possibility they offer to reduce energy consumption and for the different configurations they can be mounted.

The components of DEC system were studied in a detailed manner in the last years. Dunkle (1975) proposed a closed cycle, Hunan (1999) developed a two-stage cycle, Kang and MacLaine-Cross (1989) studied the dehumidifier. Jurinak (1982) and Kang (1990) simulated the entire system. Kodoma and al. (2000) studied the effect of desiccant wheel speed, air velocity and regeneration temperature on the performance.

Robinson (1992), Lof (1992), and Hening and al (2001) were interested in the solar integration in desiccant cooling systems. Joudi and al (2001) have simulated the effect of design parameters on the performance of the system and specifically the area of solar collectors, storage volume and effectiveness of exchangers and humidifiers for a domestic application. Halliday and al (2000) have concluded that the solar DEC system has a great potential in the UK.

Davanagere and al (1999) have accomplished a feasibility study of a solar desiccant air-conditioning system. They showed that the system has a higher COP with locations having higher latent loads. They recommended the minimization of the auxiliary energy costs employing different methods for supplying thermal energy for desiccant regeneration.

Filfli and Marchio (2005) have compared a DEC system with free regeneration energy supplying a conference room in an optimized office building where offices are conditioned with fan coil units chiller-boiler system. The free energy is recuperated from the condensers of chillers. It was shown that this choice in 18 % area conference rooms permitted 11 % savings with respect to total FCU choice system.

Solar heat, waste heat, natural gas, district heating rejection have always represented an interesting source to regenerate the desiccant wheel and as a result to save energy consumption in DEC systems and to increase their performance.

This paper exposes the methodology used for sizing elements of a solar desiccant cooling plant. The experiment is located in Chambery, east of France.

Solar heat energy absorbed by roof collectors to regenerate the desiccant wheel is proposed. A two-wheel system uses a desiccant wheel coupled with a heat exchanger wheel is mounted. The heat exchanger recycles heat for the desiccant regeneration and improves system efficiency.

The principle of DEC system combines dehumidification and adiabatic humidification process. The outside air is first dehumidified through a desiccant wheel with an increase of its sensible heat (A to B), and of its potential to use evaporative cooling. This first stage is followed by an exchange between reject air and process air by means of a heat recovery wheel, permitting to lower the air temperature (B to C). After that, water is sprayed into the process air, cooling it again (C to D), without forgetting a slight increase of the air (D') blown temperature into the local due to the fan heat dissipated into the duct.

The exhaust air is cooled by a humidifier (E to F) and is heated after that through the rotary exchanger wheel (F to G). It is reheated again (G to H) to be able to regenerate (H to I) the desiccant material in the wheel. The states of the process and exhaust air are represented on a psychometric chart.

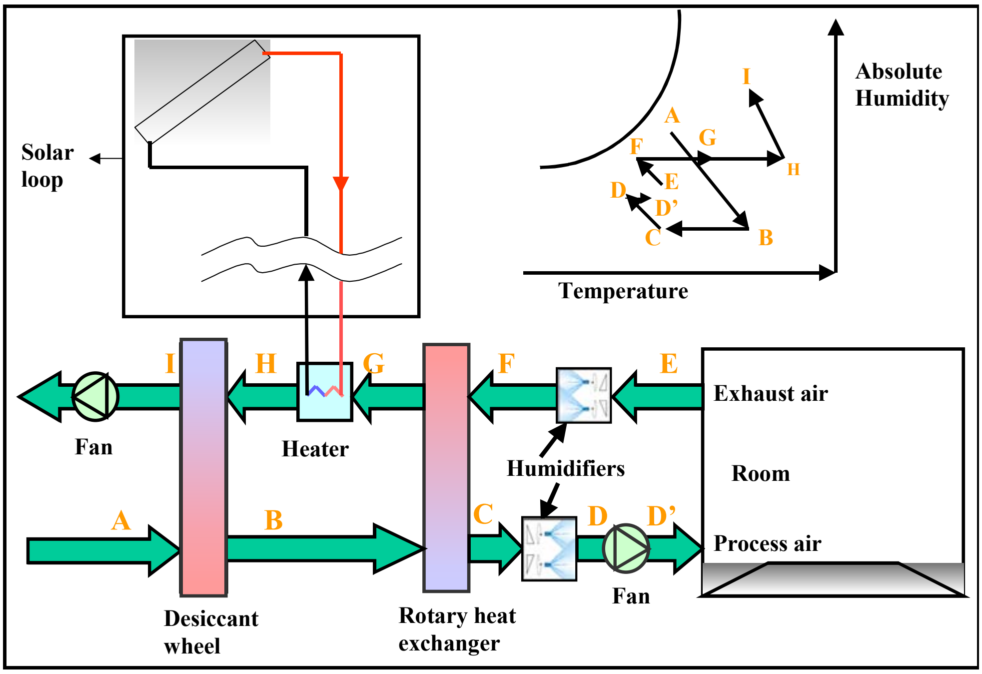


Figure 1: General scheme of solar DEC system with psychometric evolution

Description of conditioned room

The system supplies air-conditioning to the training students room of ASDER “Maison des énergies”. The heating is assured by another system (wood boiler). The solar collectors of 15 m^2 were already installed for hot water use and another applications. The choice of other elements was to be adapted for the existing surface of these collectors. The characteristics of the room are given in Table 1.

Table 1 :Characteristics of the conditioned room

Room volume	210 m^3 (70 m^2 x 3 m)
Flat liquid plate collector	15 m^2, inclined by 25°, glycol water of 40 % concentration
Glazing	23 m^2 S-W (96°), U=2 $W/m^2.K$ Solar factor/luminous transmission : 0.5/0.6 without solar shading, 0.2/0.2 with solar shading,
Occupancy	40 people from 9-12 h, 14-17 h Monday to Friday 3800 W (95 W sensible heat per person, 54 g/h or 37 W)
Internal gains	600 W (400 W - lighting, video projector 200W)
Exterior Walls	26 m^2 (opaque walls other than ceiling), U=0.4 W/m^2
Ceiling	70 m^2, U=0.2 W/m^2

The next series of photos give a more clear view of the room, which is supplied by solar DEC system. The inertia of the room is considered as medium according to the definitions of the French rules RT 2000.

Glazed facade view 1 from inside the room without solar protections

View 2 inside the room with the supply wall diffusers

Vegetable roof of the conditioned room

Solar collectors

Figure 2: Photo view of the conditioned room

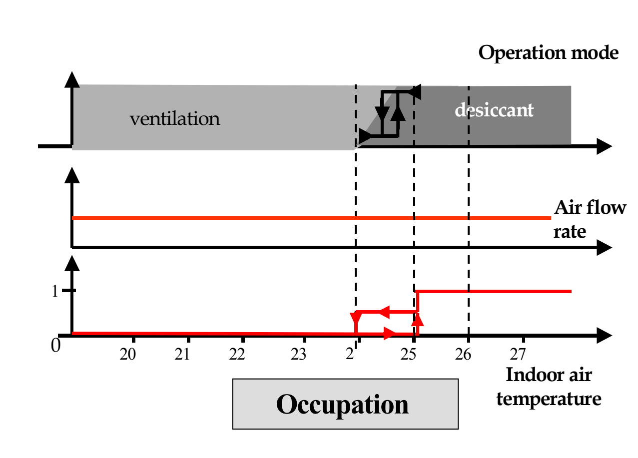
Simulation tool

The Simulation of the DEC system is done under Consoclim, a building hourly simulation program developed by CEP[1] and CSTB[2]. The model of desiccant wheel developed by Stabat (2003) using an analytical approach and the rotary heat exchanger is modeled using the ε-NTU method on the basis of the empirical formulation of Kays and London (1984). Other components models are developed in referencing to HVAC Toolkit (1993). The solar loop and its regulation process are modeled with a simple C++ program.

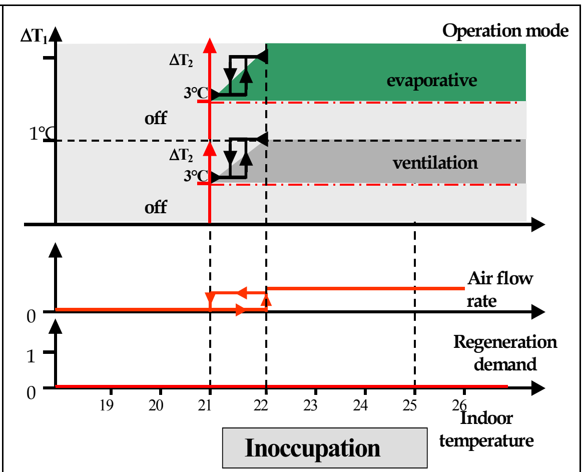
Control logic

Ginestet (2002) has developed control logic for DEC system. Under Stateflow, compatible with Matlab Simulink environment, this control is used in Consoclim. The aim of this control logic was to respect the set point of indoor temperature and to save energy as a function of presence of people in the room. Airflow rate and regeneration temperature were varied also to obtain optimal values. Due to economical factors, the experimental plant did not retain the option of variable airflow. Moreover, the solar collectors initially installed for domestic water heating are under sized for DEC application. Temperature of regeneration is chosen at Treg=50°C, it can be changed manually if necessary.

Three configurations exist for the operation of the air-handling unit. The first is the ventilation mode where only the fans and/or heat rotary exchanger are used to supply the fresh air. The second is the evaporative mode where besides the first mode components; the indirect humidifier on the exhaust air is switched on. The third is the desiccant-cooling mode where all the components of the air-handling unit are operating and the solar regeneration is active. Figure 3 shows the control strategy of the AHU as a function of occupancy and indoor temperature.



Control logic in occupation



Control logic in inoccupation

Figure 3: Control logic of AHU of a solar DEC system

Where :  indicates a hysteresis operation, $\Delta T_1 = T_A - T_{F'}$ represents the difference between outdoor air temperature and air temperature at the outlet of the regeneration side humidifier, $T_{F'}$ is calculated as : $T_{F'} = \eta.(T_E^{wb} - T_E) + T_E$, η being the humidifier efficiency, T_E^{wb} is the wet bulb temperature in E.

$\Delta T_2 = T_E - T_{D'}$ is the difference between indoor air temperature and supply air temperature.
A test on ΔT_1 compares if the evaporative cooling is more effective than ventilation. If evaporative and ventilation modes are authorized and if $\Delta T_1 > 1°C$, the DEC operates in indirect evaporative mode. A test on ΔT_2 checks if evaporative cooling or ventilation has a high potential of cooling. On this latter test, a hysteresis operation is computed in order to avoid short on-off cycles. If supply air ($T_{D'}$) is at least 4°C lower than room temperature (T_E), the HVAC system operates and if $T_E - T_{D'} < 3°C$, the HVAC system is stopped (this hysteresis operation is not represented on Figure 3).

[1] Center for Energy and Processes
[2] Centre scientifique et technique de bâtiment

This type of system has generally a limited cooling capacity due to the high temperatures of air blown in the room. This is why; the airflow rate is very high compared to other classical air-conditioning system that blows a more cold air into the room. But the increasing of the airflow rate cannot be done without regarding the speed of air (limited to 3 m/s), the pressure drop and for sure the energy consumption of the fans.

Solar loop

The heater section GH of Figure 4 is a fin tube heat exchanger. Water glycol mixture comes from solar collectors and exchanges with exhaust air in order to increase its temperature to Treg=50 °C.

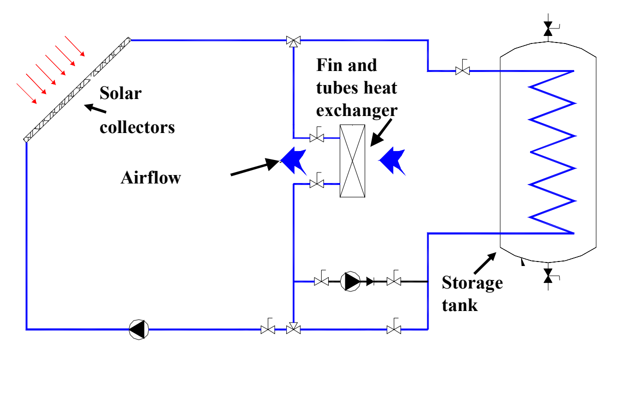
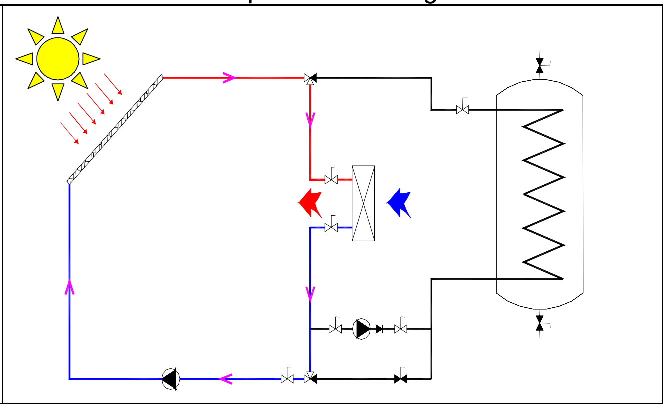
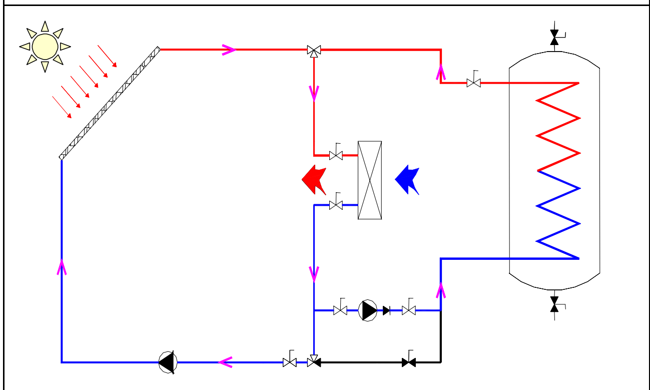
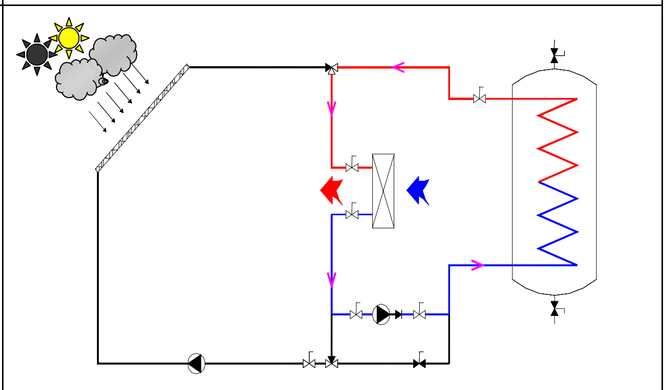
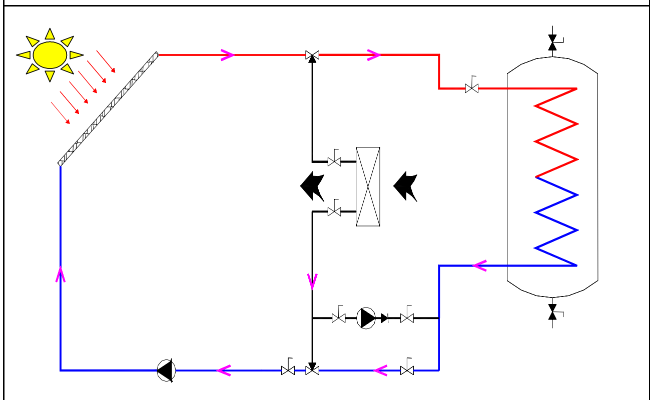
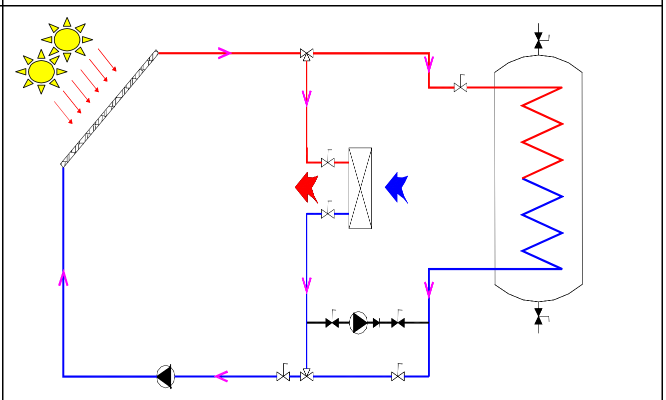
	
General representation of solar loop	(1) Solar collectors supply directly heat exchanger for heating the regeneration air
	
(2) Solar collectors and storage heat are used for heating the regeneration air	(3) Storage heat is only used for heating the regeneration air
	
(4) Storage of solar heat in the tank	(5) Solar collectors supply the heat exchanger and the storage tank at the same time

Figure 4: Different configuration of solar loop in a DEC solar system

The solar loop is configured in five-mode scheme. The transition between one configuration and another depends on the energy stored in the tank and on the needs for the regeneration. Several logi-grame are developed to translate this transition logic.

The fluid circulating inside this loop is mono-propylene glycol with 40 % concentration. This is one of the reasons that we opted for an exchanger inside the tank and not for a direct mixture tank, given that risks of sedimentation in the tank exist and to minimize quantities to add periodically.

Mode 1 - Solar collectors supply directly regeneration heat exchanger
This mode permits to exchange directly the solar heat with the regeneration air. High solar energy is a necessary condition for operation in this mode. The time operation of this mode is short, and a transition will soon be done into another mode. A variable speed pump on this circuit could represent a good choice.

Mode 2 - Solar collectors and storage tank supply regeneration heat exchanger
Flow rates from solar collectors and storage tank passes through the regeneration exchanger. If solar energy is not sufficient, complementary energy stored is added. As a consequence, this configuration is determinant in the choice of the tank volume.

Mode 3 - Storage heat is only used for heating the regeneration air
In the case where the solar potential is small, and during desiccant mode, transition to this mode is done if energy is available in the tank.

Mode 4- Storage of solar heat in the tank
This configuration is applied when there is no demand for regeneration and when the solar energy is available.

Mode 5- Solar collectors supply the heat exchanger and the storage tank at the same time
Operating in this mode occurs when the quantity of solar energy is sufficient for both regeneration demand and for storage in the tank. It is an exceptional mode.

AHU components sizing

The components to be sized in a DEC solar system are mainly : desiccant wheel, rotary heat exchanger, fin and tube heat exchanger, humidifiers, fans, solar collectors, storage tank, pumps.

Generation temperature
Taking into consideration the time where solar energy do not exist, the average of solar fluid temperature will be between 60 and 70 °C. This leads to a choice of regeneration temperature from 40 to 60°C as a function of desiccant material. We have chosen Treg=50 °C, which represents a compromise between 40 °C where the performance of the desiccant material is low and 60 °C with low probability to reach this temperature.

Airflow rate
The crucial element in sizing a DEC system is the airflow rate. CEP and CSTB (2002) have published a guideline of sizing low energy consumption systems. As a function of the climatic region (in France), regeneration temperature and internal loads, the airflow rate is given. It leads to $\dot{V}_a = 8$ vol/h which is largely beyond the necessary quantity of fresh air requested by the French regulations (25 m^3/h per person). A value of $\dot{V}_a = 1800$ m^3/h is then considered.

Desiccant wheel
The essential element for selecting the desiccant wheel is the airflow rate. In addition we will consider the following conditions :

- the exhaust air leaving the room is (25 °C , 70 % RH)
- the outdoor conditions of an average day are (28.8 °C, 11.5 °C g/kg d.a)
- the flow rates of process and exhaust air are equal (1800 m^3/h)
- Treg = 50 °C

We choose from the products of Klingenburg (2004) :
“SECO 800 / 900 – Φ 695 – thickness 450 mm”

This type of wheels is made up of cellulose fibers soaked with lithium chloride. The wheel has to turn continuously at low speeds in order to avoid any sedimentation process. The admissible interval for the regeneration temperature is between 40 and 70 °C.

Table 2 : Characteristics of selected desiccant wheel

Type	SECO H800 / L900 – Φ 695, thickness 450 mm, height 800 mm, width 900 mm, diameter 695 mm
Sensible heat	4.3 kW
Latent heat	-2.8 kW
Total heat	1.5 kW
Regeneration temperature	50 °C (from 40 °C to 70°C)
Rotational speed / motor power	20 rph / 90 W
Weight	47 kg
Pressure drop	215 Pa

A more thicker wheel is always more favorable for the performance of the desiccation process but it increases the pressure drop and as a consequence the energy consumption of the fans and the cost.

Rotary heat exchanger
The rotary heat exchanger, was chosen from the same fabricant, it is : “RRT-KT-C19-800/900 – 705 – thickness 400 mm”

Table 3 : Characteristics of selected rotary heat exchanger

Type	RRT-KT-C19-800/900 – 705 – thickness 400 mm height 800 mm, width 900 mm, diameter 705 mm
Sensible heat or Total heat	-6.71 kW
Efficiency	0.8
Rotational speed / motor power	10 rpm / 90 W
Weight	51 kg
Pressure drop	100 Pa

Humidifiers and fans
Fans requested for the plant must have high efficiency due to the fact that they constitute the first important element of energy consumption in the system. Efficiencies of 95 % and 85 % for direct humidifier (process air) and indirect one (exhaust are) are considered and are ultrasonic humidifiers.

Table 4 : Characteristics of selected fans and humidifiers

Direct humidifier efficiency	0.95
Indirect humidifier efficiency	0.85
Fans efficiency	0.8

Example of a typical day operation

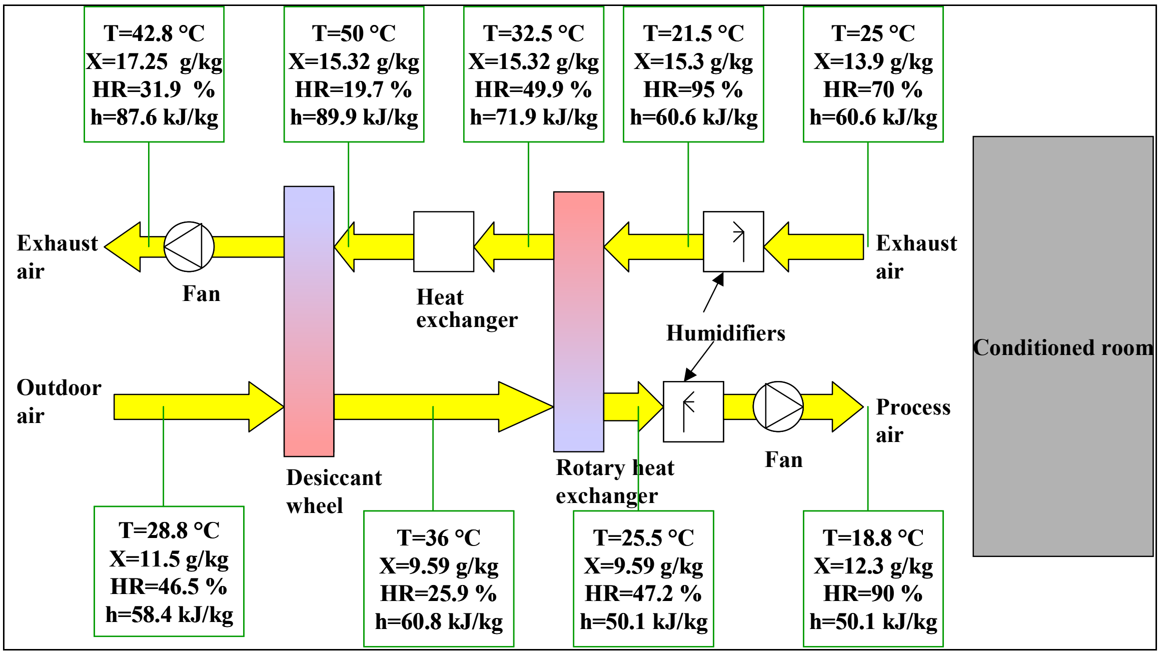


Figure 5: Temperature, humidity and enthalpy at different points of the DEC system

Solar loop components sizing

Heat exchanger for regeneration

The model of Consoclim (2005) is applied. The maximum power of this exchanger is determined in order to maintain the regeneration air at 50 °C. We consider an air at 30 °C at the inlet of the heat exchanger. The nominal power of this exchanger is then about 11 kW.

Solar collectors

A simplified model is developed for calculating the absorbed and reflected energy by the solar collector as a function of the incident angle, sun position and day of the year.

Table 5 : Characteristics of solar collectors

Water volume	6.6 liters
Masse of collector	53 kg Aluminum, 48 kg Copper, 58 kg insulation 125 kg glass, 3.6 kg silicon, 30 kg steel
Surface density	19.86 kg/m^2
Angle, Altitude, Orientation	25°, 45 °, South East
Characteristic coefficients of heat transfer	C_0=4.26 W/m^2.K, C_1 = 0,04675 W/m^{2}K^2, B = 0,73
Fluid	Mono propylene glycol, 40 % concentration

Storage tank and tube exchanger

As indicated before, the exchange between the solar fluid and the water tank is realized by a tube heat exchanger.

Figure 6 : Storage tank before and after insulation

According to the difference of temperature needed and to the values of liquid flow rate in each configuration, this exchanger was sized considering average temperatures in the tank. We consider a high insulation of the tank that limits the temperature decrease to 0.2% by hour.

Table 6: Characteristics of tube heat exchanger

Storage tank tube exchanger (Copper)	L=25 m, D_{ext}=16 mm, D_{int}=14 mm

An economical aspect was a reason to replace the copper tube heat exchanger by another polystyrene knowing that the length was multiplied by a factor of 10.

The sizing of the tank is determined after simulations over typical meteorological data and then over a period of three months in a manner to respect the set point of the indoor temperature. The size of the tank is 1500 liters. The simulation results are shown later in the paper.

Meteorological data and conditions of simulations

Using real meteorological data from Chambery, the simulations cover a summer period of 3 months : June, July and August. Wurz and al (2005) performed simulations using spark on the same plant. Besides the basic case for the simulation, we study the effect of indoor managements such as : solar shadings and lighting management.
The simulation of the system is done in two steps : first, DEC simulation with constant regeneration temperature. Second, solar loop simulation with the same meteorological conditions.

The hottest day of the summer does not implicate automatically that it is the critical day for the system, because a maximum solar energy is available. On the other hand, cooling are maximal this day which implies an increasing of the indoor temperature and therefore a maximal number of hours desiccant cooling mode.

Simulation results
Figure 7 shows the evolution of the outdoor temperature and relative humidity. Temperature reaches 33 °C as a maximum. Hour 0 corresponds to the 1st of June and hour 2184 corresponds to 30th of August. We also give the results of simulations for the indoor temperature and relative humidity with a set point of 25 °C for the same three months period.

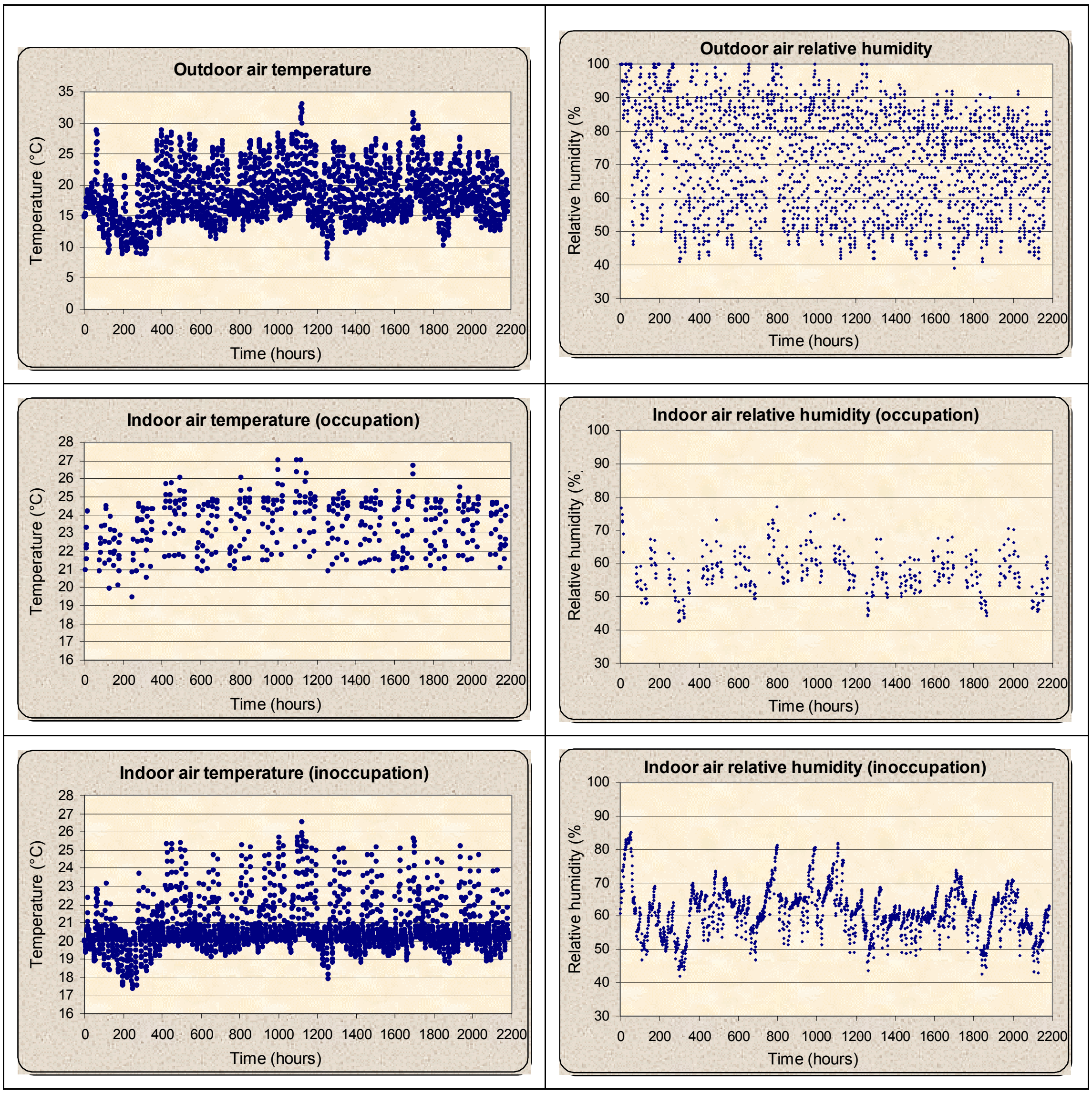


Figure 7: Outdoor temperature and relative humidity meteorological data, indoor temperature and relative humidity during occupation and inoccupation simulation results (case 1)

Figure 7 shows that the set point is not always respected during occupation as well as during inoccupation periods. This is due to the large occupancy ratio (1 person per 1.75 m^2), to important internal gains and to the choice of a medium regeneration temperature.

Indoor management effect
Table 7 resumes the number of hours where the set point is exceeded, the amplitude of this deviation (30 °C.h), the maximum temperatures in both occupation and inoccupation periods and for different managements of solar shadings and lighting. The first case of this table, which is the more current case, shows a derivation percentage of 8.4 % of the total occupation period. With a control logic that turns on desiccant operation at 24 °C instead of 25°C. Consequently, regeneration demands increase.

In addition, during hot days where deviation takes place, the solar energy allows to regenerate the wheel at temperatures higher that 50 °C decreasing the amplitude of the deviation. Lighting and shading influence are summarized in Table 7.

Table 7: Maximum value of indoor temperature and number of hours beyond the set point

3 months period simulation	Number of hours where T_{indoor}>$T_{setpoint}$ (25°C)		Maximum value of T_{indoor}, derivation in (°C.h)	
	Occupation	Inoccupation	Occupation	Inoccupation
1- Lighting ON + solar shadings	33 (8.4%)	31 (1.7%)	28.8, 30	26.5, 11.6
2- Lighting ON, no solar shadings	86 (22%)	106 (5.9 %)	30, 101.8	28, 48
3- Lighting OFF + solar shadings	22 (5.6%)	27 (1.5%)	28.3, 19.9	26.3, 9.2
4- Lighting OFF, no solar shadings	73 (18.7%)	92 (5.1%)	29.5, 73.7	27.7, 41

Table 8 shows the number of hours of operation in each mode for the four studied cases. It is obvious that more than half the total 2184 hours of simulation, the system operates in the indirect evaporative mode. The time of operation in desiccant mode varies from 8 to 13 %. Ventilation mode time is between 16 and 22 %. The AHU is off from 11 to 18%.

The total energy consumption represents the consumption of auxiliaries (mainly ventilation plus motors of wheels and humidifiers) besides the lighting and plug consumptions. The values of consumption are expressed in paying energy; primary energy can be calculated by multiplying by 2.58, factor defined by French rules. Water consumption mainly comes from indirect humidifier.

Table 8: Number of hours of operation in each mode with energy and water consumption

3 months period simulation	No. of hours in des. mode	No. of hours in evap. mode	No. of hours in vent. mode	Auxiliary consumption kWh/m^2	Total energy consumption kWh/m^2	Water consumption $l/h/m^2$
Light. ON + solar shadings	203	1245	363	25.41	28.97	90.82
Light. ON no solar shadings	321	1141	487	29.53	33.10	119.37
Light. OFF + solar shadings	183	1262	351	25.13	26.43	87.39
Light. OFF no solar shadings	289	1166	491	29.31	30.61	115.25

Supply temperature and coefficient of performance

As mentioned before, the temperature of air supplied into the room is relatively high compared to other conventional HVAC systems.

Figure 8 shows the temperature of supply air as a function of outdoor temperature for different modes of AHU. It is slightly decreasing in desiccant mode under 26°C and increasing after that as a function of outdoor temperature.

The coefficient of performance of the system can then be calculated in adding to the consumed energy, the consumption of auxiliaries of the solar loop, which are mainly circulation pumps and regulation valves.

$$COP = \frac{\text{Cooling power given to the system(W)}}{\text{Absorbed total power(W)}}$$

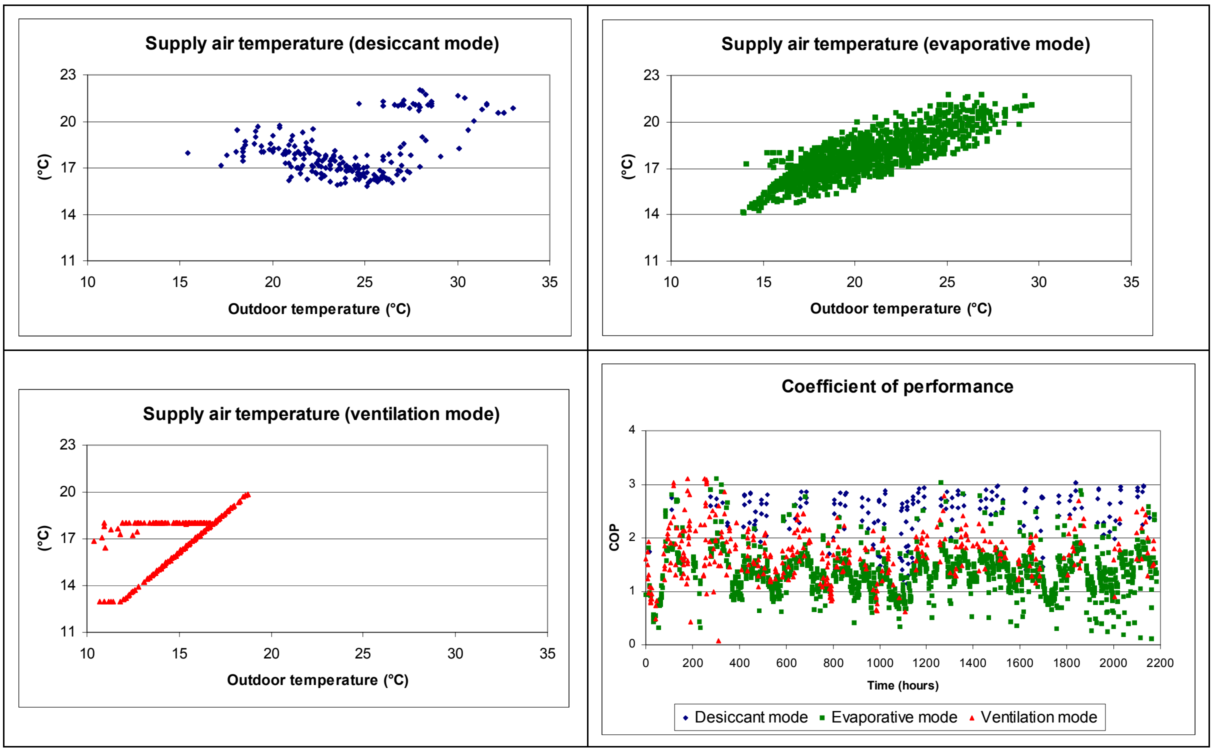


Figure 8: Supply temperature as a function of outdoor temperature in a DEC system and COP for three months period

The solar DEC system has good performances when it operates in desiccant mode. This is due to the fact that the regeneration energy is considered as a free energy. The results have to be compared to other HVAC systems when including all auxiliaries.

Regeneration power and storage tank volume

The regeneration power varies according to the temperature of the exhaust air. This power is defined as : $P_{regen} = \dot{m}_{air} . C_{peq\_air} . (T_{setpoint\_regen} - T_{out\_exchanger})$.

We consider the lighting is operating and solar shadings are in place, the room is always with maximum occupancy.

The simulation over 3 months is shown below. The temperature of the water stock initially at 80 °C seems to return to its values after two weeks. The temperature of regeneration is around 45 °C as an average.

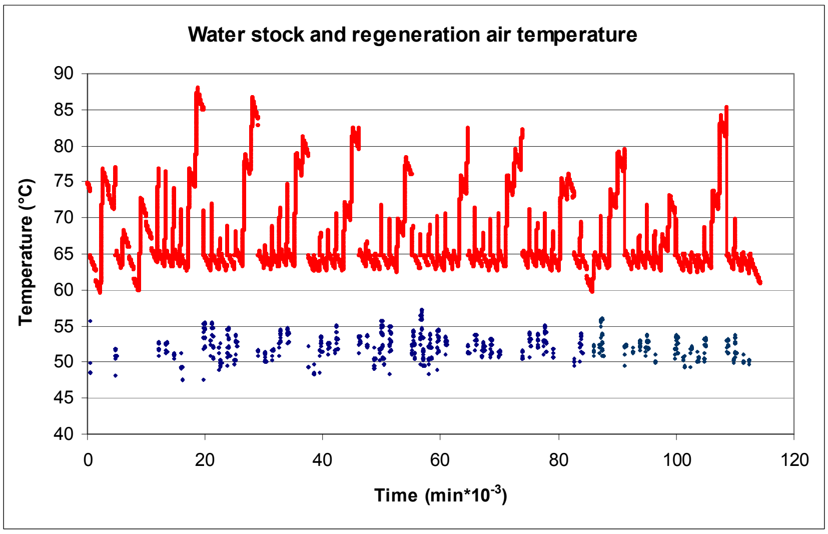


Figure 9: Temperature of regeneration air (in dark blue) and of water in the storage tank (in red) for a simulation of three months period

Indeed, the simulation did not take into consideration the control of the valve at the inlet of regeneration exchanger. A simple control can save the energy in limiting the operation to 50 °C for the days having excess heat. It is seen that the weekend has a crucial role for the energy storage in the tank. Only two modes were taken into consideration for this simulation, the mixed mode (collectors and tank supplying the regeneration exchanger) and the storage mode (collectors supplying only the storage tank). This assumption was considered in order to have extreme limits in sizing and to have a safety factor. If the system operates in other modes of solar loop (direct alimentation of collectors to regeneration exchanger or mixed alimentation to regeneration exchanger and storage tank), better results for the regeneration temperature would have been obtained. Note that some points of the stock temperature series are not represented on the figure (no stock possibility and no changing in conditions) and that regeneration temperatures represented correspond to operation in desiccant mode.

Conclusions and perspectives

This experimental bench permits to evaluate more precisely the performance of solar DEC systems. It is seen that this type of systems is only performing (low energy system) when the regeneration energy is free. It is concluded that this system can be compared to another efficient ones if we have already large fresh air needs like in supermarkets, pharmaceutical industry and conference rooms besides the improvement of the air quality it offers.

The efficiencies of chosen fans, humidifiers and pumps are very high. Low values of these efficiencies dramatically decrease the performance of the system and increases irregular operation.

The sizing procedure is presented with the recent technical products. It is seen that solar DEC systems cannot operate with high regeneration temperatures with the ratio of collector area employed. A new desiccant wheel technology is employed with regeneration temperature going from 40 to 70 °C. The system is configured to operate without calling a supplementary electrical source for regeneration. Recuperation heat can be used in other applications if necessary.

The effect of some elements like solar protections and lighting are crucial. The number of hours of each mode in the AHU is calculated with the energy and water consumption for a three months simulation. A logic control and a solar loop configuration were developed and tested.

The verification of experimental data and after that the validation of the models used in the simulations will be the next step. Simulink-Matlab environment will be used in order to go to simulate the small time steps measurements results. Improvements to the control of the system will be proposed as a function of the obtained results. This will be the object of further publications.

Acknowledgements

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Heating, Cooling and Air Conditioning with Gas-Fired Heat Pumps

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Abstract
Over the past few years, there has been a considerable rise in air conditioning and cooling demand in Germany. This sustained trend calls for the use of economical, environmentally compatible cooling processes.
Air conditioning systems are often retrofitted to existing buildings, i.e. added to existing heating systems. However, solutions combining several functions (heating and cooling) are not considered sufficiently often.
Natural gas appliances have a number of advantages: for example, gas-fired air conditioners with a compressor can develop high heat outputs at low ambient temperatures. Absorber-type air conditioners feature outstanding part-load performance and low noise levels. In addition, the operating expenses for natural gas appliances are lower than for comparable electric appliances as a result of the lower energy cost. Furthermore, the use of natural gas as a primary energy helps conserve resources and reduce specific CO_2 emissions.
This paper gives an overview of the natural gas equipment available and possible applications.

1 Introduction
For some years now, the importance of air conditioning has been growing in the commercial sector in Europe. Although Germany still lags behind other European countries such as Italy in this respect, the demand for cooling and air conditioning is still rising at the same time as a fall in commercial and industrial heating demand.

There are a number of reasons for these developments. Especially in commercial building projects, there has been a trend towards glass architecture with large window areas, resulting in considerable heating of the interior by solar radiation. The more stringent thermal insulation regulations which now apply call for buildings to have a tight envelope, which has the effect of retaining heat in the interior during the summer months.

At the same time, heat loads in many buildings are increasing as a result of the waste heat of electronic equipment. In addition, the demand for air conditioning has been boosted by heightened comfort needs. In hotels and restaurants, shops, surgeries, customer centres and leisure facilities, rooms with powerful air conditioning systems help people feel comfortable. Finally, many people are now aware of the benefits of air conditioning from their cars.

1.1 Air Conditioning Requirements
All these factors have created a growth market for economical, environmentally compatible cooling systems. Air conditioning is becoming increasingly important not only for conventional air conditioning system installation contractors but also for plumbers, architects, designers and building equipment contractors. Excessive room temperatures adversely affect people's performance. Building owners call for architects to include a cooling option in building systems in the event of high heat loads.

1.2 System Solutions

Especially for existing buildings, the conventional solution is to install a system with electric water chillers in addition to the heating system. The advantage of this solution is that heat is distributed as usual via radiators while ceiling-mounted cassettes are used for air conditioning. However, the cost of using two separate systems is comparatively high. As an alternative, electric heat pumps, such as roof-mounted multi-split units, may be used. These air/air heat pumps can make use of the heat contained in the ambient air for heating. However, there is a drastic drop in efficiency at ambient temperature below 7°C.

In such cases, gas-engine-driven heat pumps (gas air conditioners) may be a genuine alternative. These systems can provide both cooling and very efficient heating as the waste heat of the gas engine is used as a source of heat in addition to the ambient air, as in the case of a compact cogeneration plant. The coefficient of performance for heating is very high, at about 1.4 (referred to primary energy input).

Heat and cold are transferred by refrigerants, although it is also possible to use a hydraulic system, with water as the heat transfer fluid. Apart from fan-coils, heating and cooling elements can then be used for heat and cold distribution.

Another alternative for system heating and cooling is the gas absorption heat pump. Units of this type can also use other heat sources such as geothermal energy or water.

2 Heating and Cooling With Natural Gas

Natural gas air conditioners have been available in Japan for over 20 years. The reasons for the introduction of these appliances were high electric power prices and electricity supply bottlenecks caused by the increased use of air conditioning in the summer. Against this backdrop, leading Japanese gas suppliers promoted the development of gas air conditioners designed for easy switching between heating and cooling with state subsidies. Initially, these units were driven by modified automobile engines. The equipment currently available features engines especially optimized for use in gas-fired heat pumps. The Japanese market rapidly accepted gas air conditioners as an economical alternative to electric appliances; this is confirmed by the large number of 500,000 appliances installed in Japan.

In the meantime, gas air conditioners and gas absorption heat pumps with heating and cooling functions have already been introduced to the German market. Architects and building owners must therefore consider whether it is still economical to install separate heating and air conditioning systems. Investments can be significantly reduced by combining the two functions in one system.

2.1 Mode of Operation of Gas Heat Pumps

All gas heat pumps are based on a cold vapour process. A working fluid with a sufficiently low boiling point in a closed cycle evaporates at relatively low pressures and temperatures, absorbing heat from its surroundings. The vapour produced in this way in the evaporator is compressed to a higher pressure by a compressor by adding energy to the system. At the same time, the temperature of the vapour rises. In a condenser, the working fluid condenses from the gaseous to the liquid state at higher pressures and temperatures, releasing heat. The heat released in the condenser is in excess of the energy required for compression. The system is completed by an expansion valve, which lowers the temperature of the liquid working fluid to the lower pressure of the evaporator. As a result of the Joule-Thomson effect, expansion leads to temperature reduction.

This cold vapour process can be used both for heating and for cooling.

In the case of the heating function, the soil, water or air may be used as the heat source for evaporation in the evaporator. The low temperature level of this ambient heat is used to evaporate the working fluid, which is then boosted to a higher pressure and heated by compression. Industrial waste heat may also be used for evaporation, improving the overall energy balance of a process. The heat released in the condenser as a result of the condensation of the working fluid is available for space heating.

The cooling process works, as it were, in the opposite direction. The evaporator absorbs the heat needed for the evaporation of the working fluid from the building to be cooled. Following compression, the heat is normally released to the environment via the condenser. The heat sink may be the soil, water or the atmosphere.

Cold vapour processes may be subdivided into compressor processes, using compressors powered by electric motors, and absorption processes.

Significant energy input is needed for the compression of the working fluid (refrigerant) in the cold vapour state. If a similar pressure boost is accomplished in the liquid phase, the energy input required is considerably lower. The absorption process is based on this physical effect.

Downstream from the evaporator, the gaseous refrigerant is liquefied by a solvent which absorbs the refrigerant. The energy released as a result of absorption may be used for heating. The liquid mixture of solvent and refrigerant is boosted to a higher pressure by a pump. In the generator, the refrigerant is evaporated and separated from the solvent, which remains in the liquid state as it has a higher boiling point. Heat is required for the separation process. The solvent is pumped back to the absorber for the absorption of refrigerant via an expansion valve, where its pressure is reduced. The gaseous refrigerant is fed to the condenser, where heat is released by condensation.

The refrigerant passes via an expansion valve where its temperature is reduced and is then available to absorb heat in the evaporator.

2.2 Gas Air Conditioners

Gas air conditioners may be operated with a refrigerant or water as the operating fluid. As a result they are not only available for new buildings but are also an attractive solution for existing buildings as they can easily be integrated into the normal systems.

2.2.1 Gas Air Conditioner and Direct Evaporation Systems

Air conditioners driven by gas engines may be installed in split or multi-split systems operated on the VRF (variable refrigerant flow) principle (Fig. 1). These systems consist of an outdoor unit and the appropriate number of indoor units. Heat and cold are transferred between the outside and indoor units by a refrigerant. In the indoor units, the refrigerant is evaporated for air conditioning or condensed for heating. The refrigerant flow varies as a function of the heating or cooling load on the indoor units.

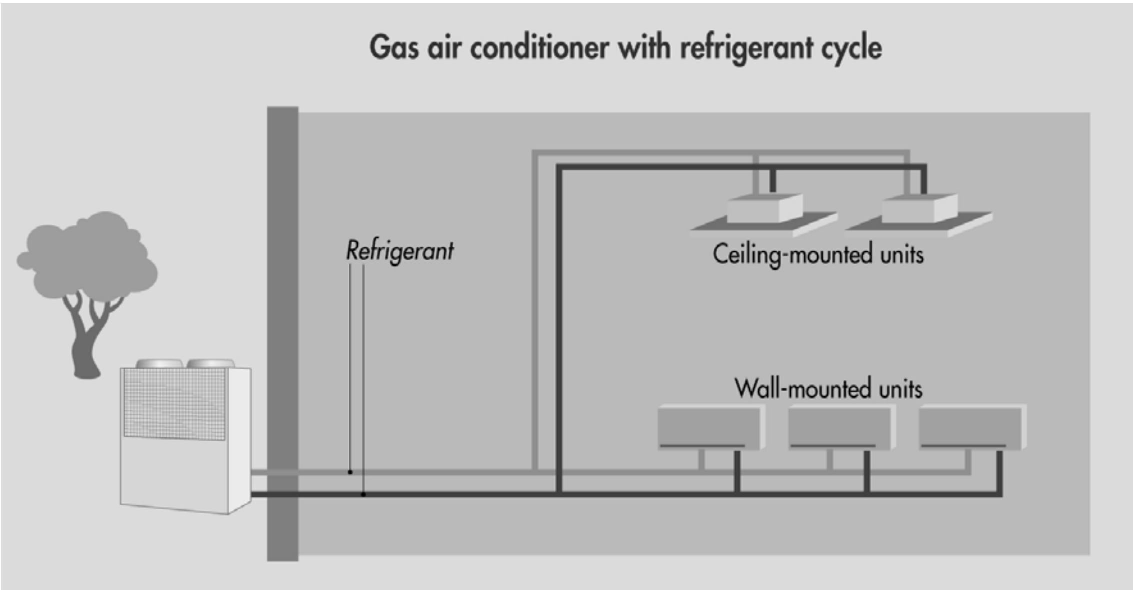

Fig. 1: Multi-split system with gas air conditioner. Energy is transferred via a refrigerant cycle. The refrigerant flow is a function of the heating or cooling load on the indoor units.

2.2.2 Gas Air Conditioner and Hydraulic Systems

Heating and air conditioning systems with water as the heat transfer fluid are in more widespread use in Germany than VRF systems. For such applications, gas air conditioners may be combined with a hydraulic transfer station (Fig. 2).

This hydraulic transfer station forms the interface between the refrigerant cycle (between outdoor unit and transfer station) and the water system (between the transfer station and the indoor units). The combination with a hydraulic transfer station allows the entire range of water heating and cooling systems, such as fan-coils, ceiling-mounted units, induction units, heating/cooling ceilings and hollow-core concrete tempering to be used. The hydraulic transfer station may be installed in the building. This avoids the risk of freezing to which electric water chillers are exposed.

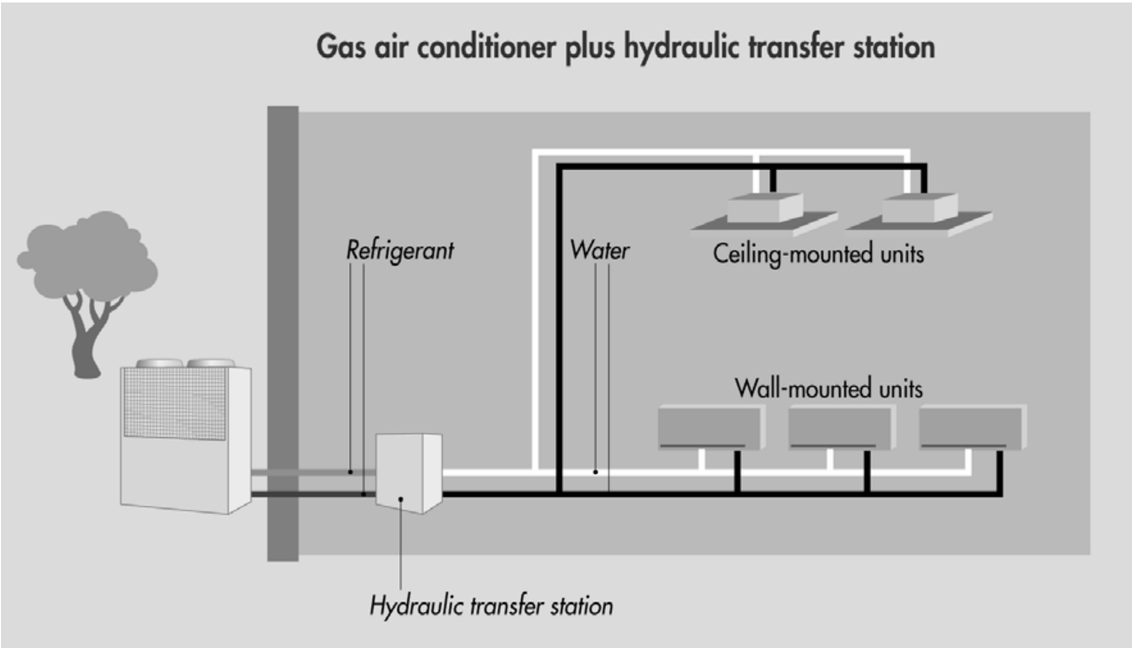

Fig. 2: Gas air conditioner combined with a hydraulic system. A hydraulic transfer station forms the interface to the refrigerant system of the outdoor unit.

2.2.3 Multiple Benefits

The gas air conditioners available in Germany to date can either heat or cool and are designed for switching between the two functions. For this purpose, the flow direction of the refrigerant is reversed. This switchover is accomplished for the entire system using a four-way switchover valve. The latest generation of gas air conditioners, with three-pipe systems, also allow simultaneous heating and air conditioning.

In **heating operation** (Fig. 3), the compressor pumps the gaseous refrigerant to the indoor units, where it condenses, transferring heat either to the room or to a heating fluid (water) in a heat exchanger.

In **cooling operation** (Fig. 4), the flow direction is simply reversed. The liquid refrigerant is pumped to the room, evaporates in the indoor units, absorbing heat from the room which is rejected in the condenser. In cooling operation, the system also offers a dehumidification function.

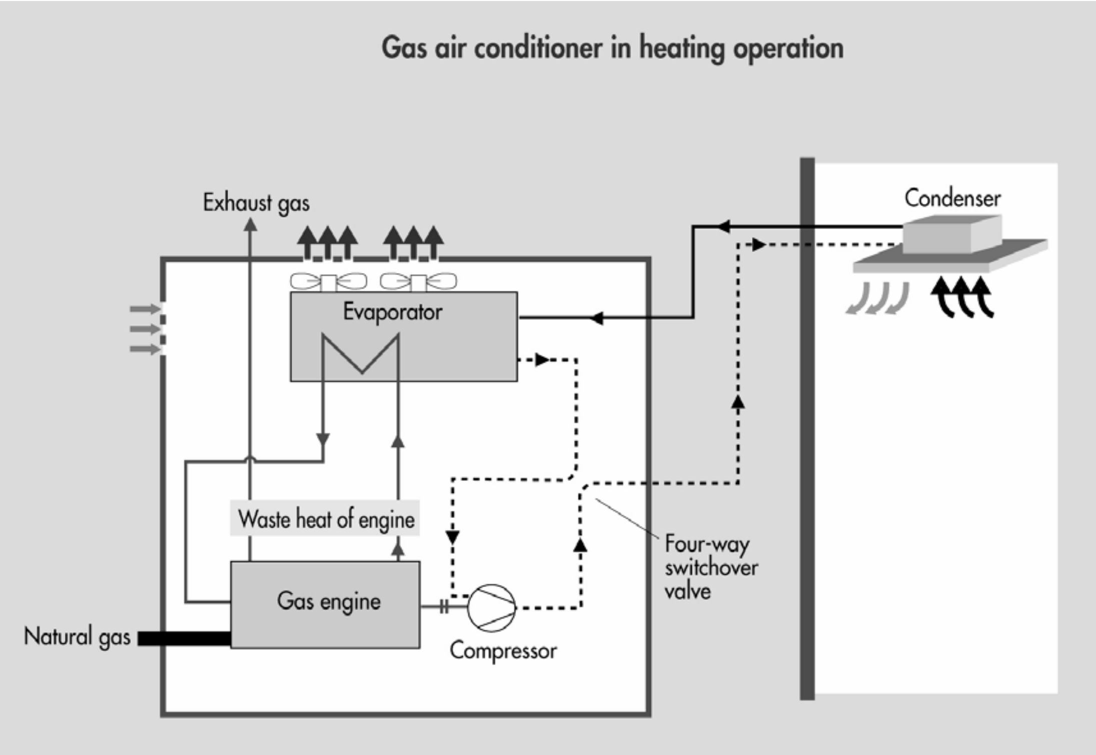

Fig. 3: **Gas air conditioner in heating operation. The gaseous refrigerant condenses in the indoor unit, emitting heat into the room.**

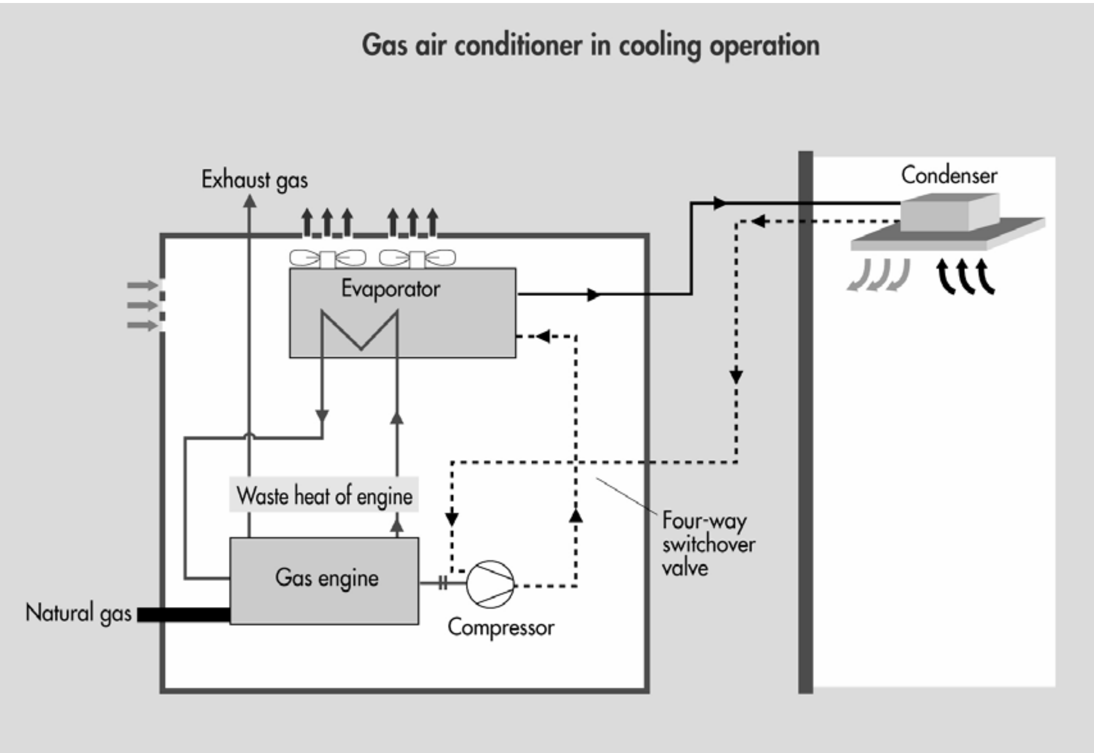

Fig. 4: **Gas air conditioner in cooling operation. The liquid refrigerant evaporates in the indoor unit, absorbing heat from the room.**

2.2.4 Environmental Benefits

The growing energy demand for air conditioning is a serious global problem resulting in power supply bottlenecks and rising greenhouse gas emissions in many regions of the world.

Gas air conditioners help to alleviate this problem. Gas air conditioners and gas absorption heat pumps save primary energy by avoiding the losses associated with power generation. In addition, it is normally possible to avoid an increase in the power rating of buildings and higher power demand in the critical summer months.

Fig. 5 compares the annual carbon dioxide emissions of a gas air conditioner and a conventional solution with a heating boiler and an electric water chiller. As a result of the high coefficient of performance in the heating mode, it is possible to reduce carbon dioxide emissions by about 30 percent in the case considered. There are also significant reductions in pollutant emissions.

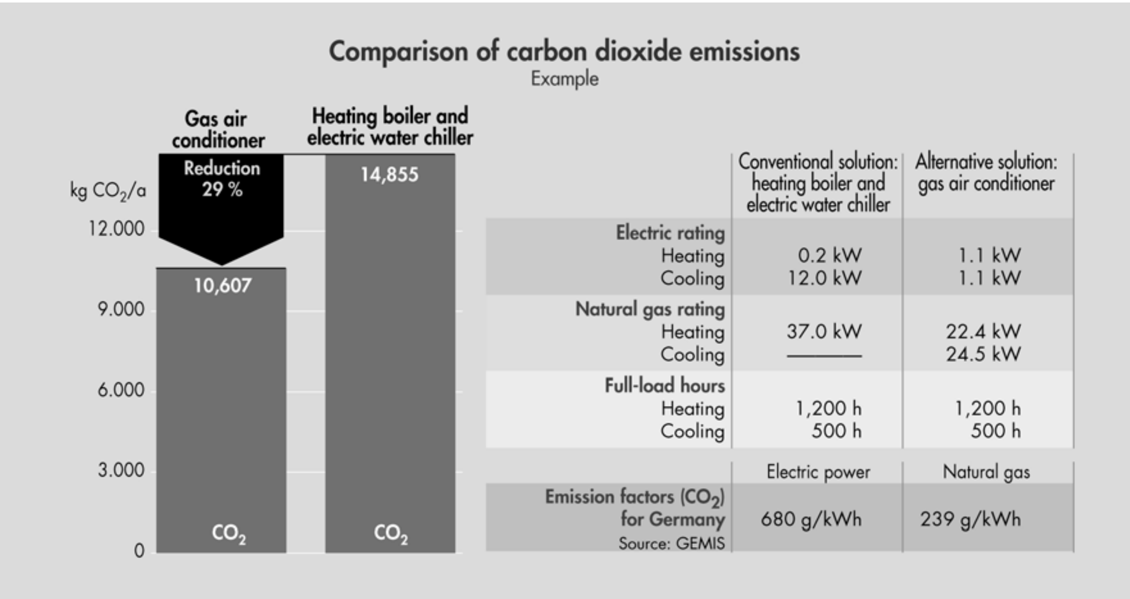

Fig. 5: Comparison of annual carbon dioxide emissions with a gas air conditioner and a combination of heating boiler and electric water chiller

3 Gas Heat Pumps in Germany

Over the past few years, Japanese gas air conditioners with cooling ratings from 14 to 56 kW and heating ratings from 18 to 67 kW have been introduced to the German market. In some cases, existing infrastructure is used for sales and servicing, such as the networks of Kaut, Wuppertal, and Stulz, Hamburg. Other companies such as Berndt, Gelsdorf, and Panitz, Lieskau, have developed new structures. The total number of gas air conditioners installed in Germany as of October 2005 in a variety of applications was 73. The locations are shown by Fig. 6. The total rating of all the units installed in Germany is currently about 2.2 MW for air conditioning and almost 2.7 MW for heating.

Fig. 6: Projects with gas air conditioners completed in Germany (as of October 2005).

As regards absorbers, the Italian company Robur has offered a new series of heat pumps for cooling and heating since 2004. These units can use a variety of heat sources and in some cases offer simultaneous heating and cooling functions. These heat pumps are distributed by Isocal HeizKühlsysteme of Friedrichshafen and Kaeltro Kältetechnik of Berlin.

4 Applications and Economics of Gas Heat Pumps

Absorbers for the industrial and commercial sectors have been available on the German market for many years and are offered by companies such as York, Carrier, Trane, Robur, Broad Air etc. They are available in many different sizes. The projects which have actually been realized indicate the applications in which adsorption systems are technically feasible and commercially viable. One of the special advantages of absorbers is the fact that it is possible to use waste heat. Absorbers are virtually free from wear, require little maintenance, have low noise levels and demonstrate outstanding part-load behaviour. They can also be used in combination with cogeneration plants and gas turbines as well as in district heating systems.

Gas air conditioners are especially well-suited for buildings requiring heating ratings between 18 and 67 kW and cooling ratings between 14 and 56 kW or multiples of these figures. The modular design of these systems means that it is possible to meet almost any performance requirements. If the existing heating system needs to be expanded or replaced or in the case of a new building, gas air conditioners can be used for both heating and air conditioning. Applications which are especially interesting are hotels, restaurants, offices and administrative buildings, customer centres, commercial operations, shops and computer centres. It is also possible to integrate these units effectively if the heat or cold source of a heating and air conditioning system needs to be replaced.

The combination of heating and cooling functions in one unit has economic benefits, as indicated by Fig. 7, which compares the conventional heating boilers and electric water chillers currently in widespread use with a gas air conditioner combining the two functions.

The example is based on an office or administrative building with a heating demand of 33 kW and a cooling demand of 28 kW. The total cost of the heating boiler including the ancillary systems required (flue system, heating piping, radiators and possibly oil tank) and the electric water chiller complete with infrastructure (refrigerant piping, wall-mounted or ceiling-mounted indoor units) is estimated at about € 65,000.00. On the other hand, the total investment for the gas air conditioner including pipework and infrastructure is about € 52,000.00. The cost saving is the result of the use of the same generation and distribution systems for both heating and cooling. This approach significantly improves the economics of the project. Normally, solutions for the rational use of energy entail higher initial investment which is only recouped through lower energy costs when the equipment is in service. In this case however, a gas air conditioner reduces both the initial expenditure and later energy costs.

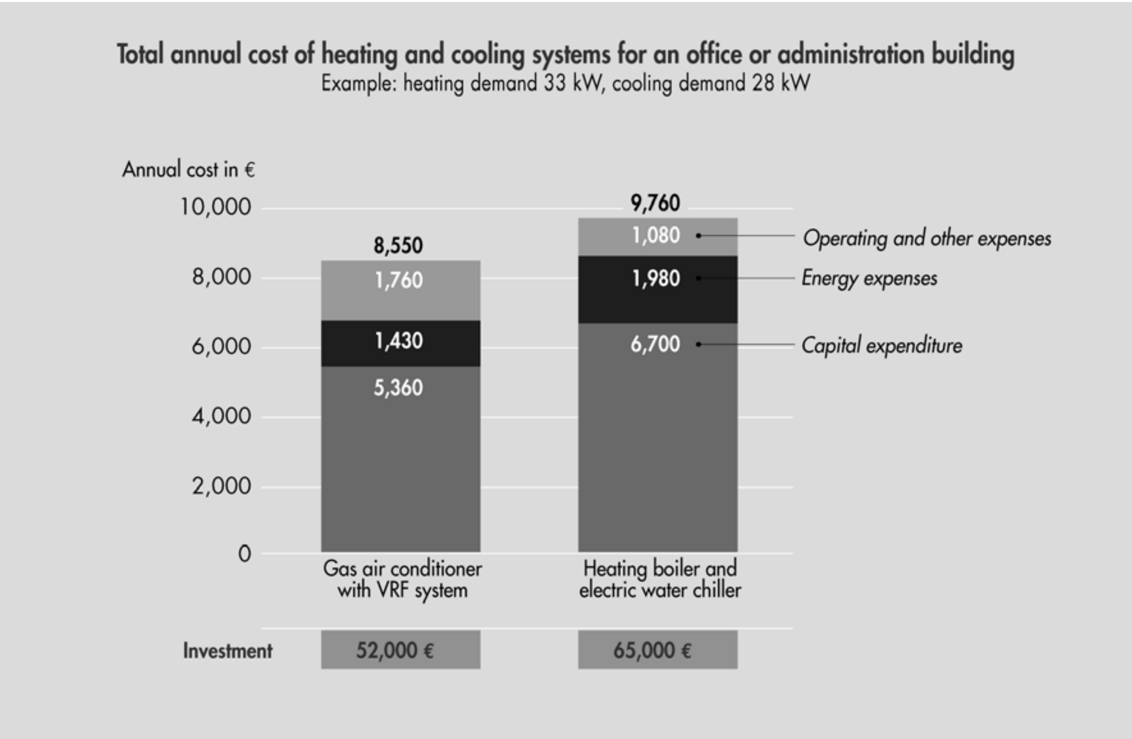

Fig. 7: Full-cost comparison in accordance with VDI Code 2067 of a gas air conditioner and a conventional solution with a heating boiler and an electric water chiller, based on year-round heating and cooling of an office building.

This advantage also explains the lower annual total cost in the case of a full cost calculation in accordance with VDI code 2067. The annual cost with the gas air conditioner is about € 8,600, while the cost with a heating boiler and electric water chiller is about € 9,800. In this example, the gas air conditioner therefore has an annual cost advantage of € 1,200.

A key factor in the viability analysis is the tax treatment of the natural gas used for the air conditioning system. Before the gas air conditioning system is commissioned, the operator must apply to the customs authorities for a permit under the Mineral Oil Tax Act as the system includes an internal combustion engine. When the operator has obtained a permit, he can apply to the customs authorities annually for the repayment of the natural gas tax, currently amounting to 0.55 ct/kWh, paid with his gas bill. The tax is repaid by the customs authorities if it is possible to demonstrate that the plant is used for more than 70% of the time over the course of the year. If this is the case, the economics of the example considered are improved still further.

5 Summary and Outlook

The energy demand for cooling and air conditioning in Germany is steadily growing, especially in the case of projects with a cooling demand of up to 100 kW. To date, mainly electric appliances have been used. Gas air conditioners are an alternative that not only saves cost but also helps conserve primary energy resources. The new generation of gas-engine-driven air conditioners was developed in Japan and is offered by three Japanese companies via a number of sales partners in Germany. Gas air conditioners may be used for both heating and cooling. The combination of heating and cooling functions makes gas air conditioners considerably more economical than separate systems for cooling and heating.
It is feasible to cover heating, cooling and air conditioning requirements with the gas-engine-driven systems and absorbers available using natural gas as the primary energy. The technology is tried and tested and has been used successfully in practice for many years. The range of equipment available is already very wide and is growing steadily.

Gas engine and absorption processes have considerable energy saving advantages over conventional cold vapour processes using electric power. Natural gas systems of this type can also significantly reduce emissions of greenhouse gases and pollutants from air conditioning systems.

The technical advantages of heating and cooling with gas air conditioning systems are summarized briefly below:

- Proven equipment technology, no prototypes or pilot plants
- High reliability and low maintenance requirements
- Flexible adaptation of output by engine speed control
- Individual control possibilities
- Very low fall in heating performance at low outside temperatures ($T < 7°C$)
- Short warming-up phase with rapid availability
- No interruption of heating to thaw evaporator

In economic terms, gas-engine-driven systems and absorbers are an interesting alternative to conventional technology for many applications. The reason for the rather hesitant acceptance of these systems to date is probably a lack of information and a certain knowledge deficit. In order to avoid later problems for operators, considerable experience is needed for the design and installation of these systems.
Heating and cooling with a single system generates benefits. The financial expenditure for the heating and cooling of buildings may be reduced, helping to improve the competitiveness of a company. In addition, these systems allow a sustained and sustainable reduction in environmental loads.

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Current and future energy demand of ICT appliances in offices – a recent assessment for Germany

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Abstract

Electricity consumption of ICT appliances has grown steadily over the past years. In Germany, the electricity demand for information and communication appliances and the associated infrastructure for networking in offices was investigated based on a stock model. In 2004, the total electricity demand for the use of end-use devices in offices in Germany amounted to 7.2 TWh, of which almost half of it for standby. But the standby consumption could be reduced by more than 50 % through technical optimization of the appliances. Political instruments are recommended in order to promote the market diffusion of appliances with low standby consumption.

1 Introduction

Energy consumption and the resulting CO_2 emissions in the commercial/service sector (or tertiary sector, as it is often called) are playing an increasingly important role in many countries. Electricity consumption, in particular, has grown steadily over the past years. This is mainly due to an increase in demand for information and communication appliances and their associated infrastructure. In the EU-25 countries, electricity consumption in the tertiary sector increased by 3 % per year in the EU-25 countries – and a further increase is expected of more than 2 % per year during the next 15 years. For electricity, the EU study “European energy and transport trends to 2030” projected a further increase of more than 2 % per year during the next years. As a result, this sector, and especially its electricity consumption, has become the target of energy policy initiatives to improve energy efficiency at international, national and local levels. A special focus is on standby consumption which continues to be significant world-wide since the number of electrical appliances with standby components is constantly increasing.

However the information basis on the tertiary sector with its very heterogeneous economic and energy-related structure, the availability of detailed data concerning electricity consumption and its use by purpose is still scarce. The disaggregation of electricity use is much more difficult than structuring heat demand. However sufficient data are a precondition for measures and policies to achieve electricity savings.

But increasing efforts - both at the national level and at the level of the EU and IEA - are made to improve the knowledge base of the commercial/service sector's electricity use and its driving factors. A special focus of many studies is on electricity consumption of ICT appliances, especially its standby consumption (see e.g. IEA 2001, Roth et al. 2002/2004). Within the programme "Intelligent Energy Europe"[1], a lot of projects are supported dealing with electricity consumption in the residential and commercial sector. The new EU project "Monitoring Electricity Consumption in the Tertiary Sector (EL-TERTIARY)" e.g. aims at providing reliable and valid data on electricity consumption in the tertiary sector obtained through empirical methods. A further objective is to find out factors determining energy consumption such as sector-specific technical equipment, user behaviour and others, in order to identify options for efficiency improvement regarding investments in equipment as well as behavioural changes. First results of the project will be available in summer 2006.

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1 http://www.eu.int/comm/energy/intelligent/index_en.html

In Germany, two empirical surveys have been carried out on energy consumption in the commercial sector since the mid 1990s (Geiger et al. 1999; Schlomann et al. 2004). A new survey has begun in autumn 2005 by Fraunhofer ISI, GfK and the Technical University of Munich, based on face-to face interviews in more than 2 000 workplaces. First results of this survey on behalf of the Federal Ministry of Economics and Technology (BMWi)will be available in summer 2006. The surveys provide a statistically database for quantitative analyses of energy consumption and its structural and economic determinants at the level of specific branches. Additionally, the energy consumption of information and communication technology (ICT) in office buildings was investigated in detail (Cremer et al. 2003; Schlomann et al. 2005). This paper discusses the methodological approach and the main results of the recent ICT survey on behalf of the BMWi. A special focus is on standby consumption of office appliances and the possibilities to reduce this important part of electricity consumption.

2 Methodology

Due to the growing importance of electricity consumption of ICT appliances including its standby consumption, it makes sense to take a closer look at this. In Germany, the electricity demand for information and communication appliances and the associated infrastructure for networking in offices was investigated in detail in two surveys (Cremer et al. 2003; Schlomann et al. 2005), using the same methodological approach. The methodological approach was based on a stock model consisting of the following components (Figure 1):

- the current stock of ICT appliances or uses;
- electricity consumption of the appliances in the different operating modes (normal operation, standby mode, off mode) as well as the energy consumption of the underlying infrastructure;
- operating times in the various modes, i. e. the respective intensity of use.

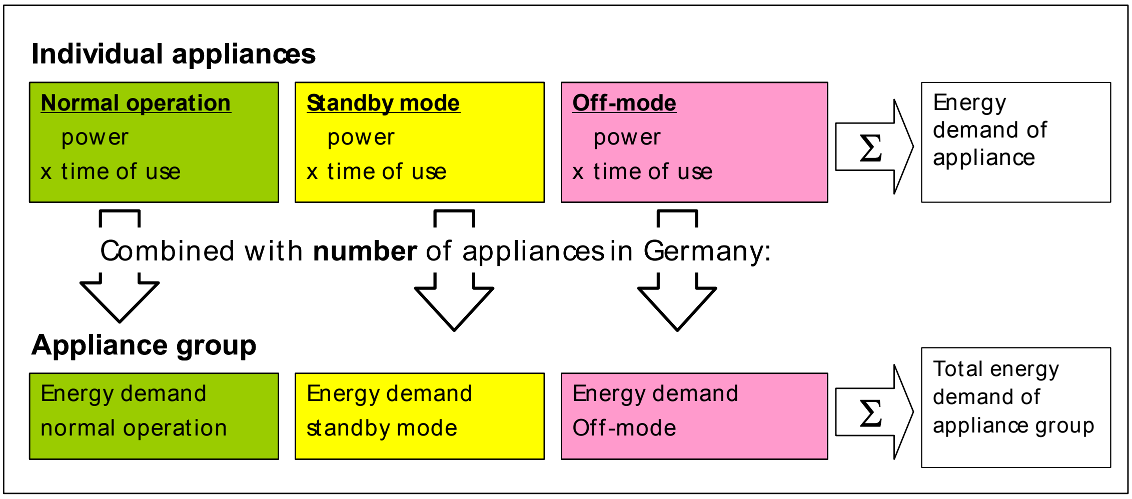

Figure 1. Model to determine the power demand of ICT appliances and the associated infrastructure in offices

Modelling the power demand of electrical office appliances was done for the benchmark years 2001 and 2004 as well as 2010 and 2015 (as projections). In doing so, the following modes of operation were distinguished: normal operation, standby mode[2], off-mode, off. Table 1 shows the list of office appliances included in the study. In the following, the main focus will be on end-use devices in offices. The energy consumption for infrastructure will only be shortly summarized from Cremer et al. (2003), since these data were not updated in the new study. Apart from a "business-as-usual" scenario as a reference, a technical saving potential was calculated for standby consumption of these appliances.

2 Within the standby mode, distinctions are made between the three modes "ready", "standby" and "sleep", depending on the reduction in energy consumption due to the restriction in functions.

Table 1. List of office appliances included in the study

Main group	ICT end-use devices	Building-internal infrastructure
Communications	**Telephone (fixed network)** Cordless telephone (DECT) Smart phones Answering machines[1] Fax machines	**Networking** Router Hubs/Switches **Telephone/Other** Private branch exchange Intercom
Data processing	**Computers** Personal Computer (PC) Notebook PDA **Monitors** Cathode ray screen Flat screen **Printer** [1] Ink jet Laser Matrix **Other devices** Scanner Beamer	**Server** **UPS**
	Copiers	
1 Incl. Combined appliances		

3 Results

Appliance stock

Estimating the current stock of relevant ICT end-use devices in offices and its development up to 2015 was done using the number of employees in office occupations or similar jobs and the standard equipment of office workplaces with information and communication end-use appliances. This means that both offices belonging to the tertiary sector and to the industrial sector were included. The group of those employed in office occupations has become much more significant over the past few years and will probably rise from around 11.75 million in 2000 to around 12.6 million by 2010 (Weidig et al. 1999). Assessing the equipment of office workplaces in Germany with ICT end-use appliances was done based on the most recent 1998/99 survey of the Federal Institute for Vocational Training (BIBB) and the Institute for Employment Research (IAB) on the qualifications and employment situation in Germany (Dostal et al. 2000; Troll 2000). These surveys were supplemented in individual cases by referring to the statistics of associations and market and opinion research institutes. The number of ICT end-use appliances in the office sector for the years 2001 and 2004 as well as for the projections 2010 and 2015 results as the product of the number of employees and the respective level of equipment (see Annex 1). The following trends can be seen:

- In the field of communications, almost all the office workplaces in Germany today are equipped with *fixed network telephones*, but approx. 40 % still have simple telephones. Their number will drop sharply up to 2015, whereas the number of smart and cordless phones, which are relevant for power consumption, will grow by about a fifth from 10.9 million in 2004 to 13.2 million in 2015. In contrast, answering machines, which are widespread mainly in small offices, are showing signs

of reaching saturation level since these devices are being increasingly integrated in other appliances. In order to maintain contact with their customers via different media, businesses will increasingly switch to multifunctional devices.
- A continued increase in *office computers* is estimated from around 17.5 million today to almost 19.4 million in 2015. However, this is entirely due to the expected strong growth in notebooks, whereas the number of today's predominant desktop computers will probably stagnate at around 10.5 million by 2015. Accordingly, there will no further growth in the number of monitors either. Here, LCD screens will completely replace cathode screens by 2010. Only a slight increase in stock is anticipated for *printers, scanners and copiers* in the next decade.

Power Consumption

The respective power input used in the model for the years 2001 and 2004 in normal, standby and off modes is based on measurement values given in the literature or our own measurements. The estimates made for the years 2010 and 2015 take into account both expected increases due to higher design and performance requirements and decreases in power consumption due to autonomous technology progress or already ongoing measures to increase energy efficiency (esp. Energy Star).

For the development of power consumption in normal mode between 2001 and 2010/15 was only assumed for a few appliance groups in **normal mode,** no significant changes are expected for a lot of these appliances. Technical possibilities to reduce the power demand are usually compensated or often even overcompensated by increased (use) performance or additional functions especially for ICT appliances. For this reason, it was assumed that power input remains constant between 2001 and 2015 in normal mode for appliances which are already technically mature and for which there is no marked demand for increased performance or complex additional functions (fixed network telephone devices, PDAs, scanners, printers, copiers). For PCs, notebooks and LCD screens, a slight increase of power consumption in the normal mode is assumed at least until 2010 because of continued increases in performance or convenience requirements which outweigh the technically feasible consumption reductions (see Annex 1). Whereas the power consumption in normal mode is expected to remain constant of slightly increase for a series of office appliances up to 2010/15, the opposite tendency was observed in **standby mode** between 2001 and 2004. Current measurements for the majority of appliances show a decrease in power consumption, although this turned out to be only moderate in many cases. The most obvious drop was seen in PCs, notebooks and LCD monitors. The expected decrease in standby power consumption of desktop computers is primarily due to the integration of more efficient power supply units (PSUs), the increasing use of mobile processors and a greater use of power management systems. As regards notebooks, it is assumed that the chip industry will make a concerted effort to increase energy efficiency in order to further extend the operation time of mobile appliances. On top of this, towards the end of the period under observation, OLED monitors could come into operation which are more efficient than today's LCD screens. For copiers in offices, which are frequently used as multifunctional devices in combination with printers, a clear drop in standby power consumption is reckoned between 2004 and 2010 due to more efficient technical solutions for the rapid shift from standby to copy mode. A continued moderate decrease in power consumption is also assumed in **off-mode** for the majority of office appliances for which this operating mode is relevant (computers, PDAs, monitors, inkjet printers). Under these assumptions, the majority of appliances will still consume over 1 W of power in this technically actually superfluous operating mode in 2010 (see Annex 1).

Operating times

In the office sector, there are no regular surveys of **operating times** of ICT appliances available in Germany. The times selected here for the various operating modes represent our own estimations based on existing figures in the literature. The following framework assumptions are made: the appliances are in operation for the usual office hours, on average eight to ten hours and 220 working days per year. The appliances are not used continuously during this time, but are permanently on standby.

Total consumption

According to the bottom-up analysis, the total electricity demand for the use of end-use devices in offices in Germany amounted to 7.2 TWh in 2004, which was almost the same amount as in 2001

(Table 2). An additional consumption of 7.7 TWh is caused by the power demand of the ICT infrastructure in offices (above all for servers). Up to 2010/2015, a decrease in electricity demand for end-use appliances in offices by about 1.5 TWh is assumed. This is mainly due to the assumed drop in standby power consumption of computers, monitors, printers and especially copiers during that period (see Table 3). Additionally, a rising share of notebooks compared to desktop computers will also contribute to this decrease. With regard to the power demand for the infrastructure in offices (esp. for servers), a further growing is assumed.

Table 2. Total electricity consumption for ICT equipment in offices in Germany 2001/2004 and 2004 and forecast to 2010/2015 (BAU scenario)

	2001 GWh	2004 GWh	2010 GWh	2015 GWh
ICT end-use appliances in offices	**7318**	**7272**	**5727**	**5478**
Cameras	5	4	3	3
Telephony (fixed network)	695	831	849	871
Computers	1579	1597	1624	1439
Monitors	1760	1438	656	673
Printers	810	883	686	695
Others (copiers, scanner, beamer)	2469	2519	1910	1797
ICT infrastructure in offices	**5425**	**7726**	**11101**	
Networking (router, hubs/switches)	665	808	1032	
Servers	3945	5800	8791	
Others	815	1118	1278	
Total	**15462**	**14998**	**16828**	

Sources: Cremer et al. 2003; Schlomann et al. 2005

Table 3. Standby electricity demand by ICT equipment in offices in Germany 2004, 2010, 2015 (BAU scenario)

ICT end-use appliances in offices	2004 GWh	2010 GWh	2015 GWh
Cameras	3	2	2
Telephones	725	733	753
Computers	389	234	159
Monitors	240	115	118
Printers	623	415	353
Others	1413	706	527
Total	**3391**	**2203**	**1912**

Source: Schlomann et al. 2005

4 Technical energy saving potentials for standby consumption of office appliances

In the study of Schlomann et al. (2005), the technical energy saving potentials to reduce energy consumption of office appliances were only analysed with respect to standby consumption (incl. off-mode). These calculations were done by the Research Institute for Energy Economy (FfE) in Munich. To determine the saving potentials in standby mode, it is necessary to differentiate between the standby states in more detail (see Chapter 2). The energy consumption depends on the respective functions and tasks of the components in the appliances. This is why appliances were split into functional sub-groups and analysed with regard to their relevance in the specific operating modes. The criteria used were the main task and the electro-technical implementation relevant for this:

- *Energy supply and transformation*: all the appliances examined here draw electricity from the mains; some have an additional power supply via storage batteries to maintain power for storage elements etc. Since the appliances not only use the 230 V power pre-set in the mains, but also require deviating voltages for sub functions, they are equipped with adaptors which are either incorporated into the device or externally plugged into the wall outlet. Usually, transformers are used. Cathode ray monitors require separate high-voltage power supplies.

- *Control electronics* for appliance functions, programming and processing operations, to save settings and in data processing for the computing power function with microprocessors.
- *Signal processing*: recording or receiving analogue or digital signals, e.g. transceivers of aerials, remote controls etc.
- *Information visualization* to display standby state or a certain function, e.g. LEDs on switches or buttons, displays, programmable LCD displays or touch screens.
- *Electrical engineering*: components powered by an electric motor such as disc drives, transport devices, vibrating elements, pumps, fans etc.

There are potentials to reduce standby losses depending on the appliance category and the functional unit. In the most straightforward case, the standby consumption can be avoided by integrating a primary-side power switch. However, this is the case in only a few appliances. It is much more common to find functional units being operated in standby or off-mode. In these cases power consumption occurs not only to supply these functional units but also for the PSU. The decision tree in Figure 2 illustrates the basic procedure for determining saving potentials.

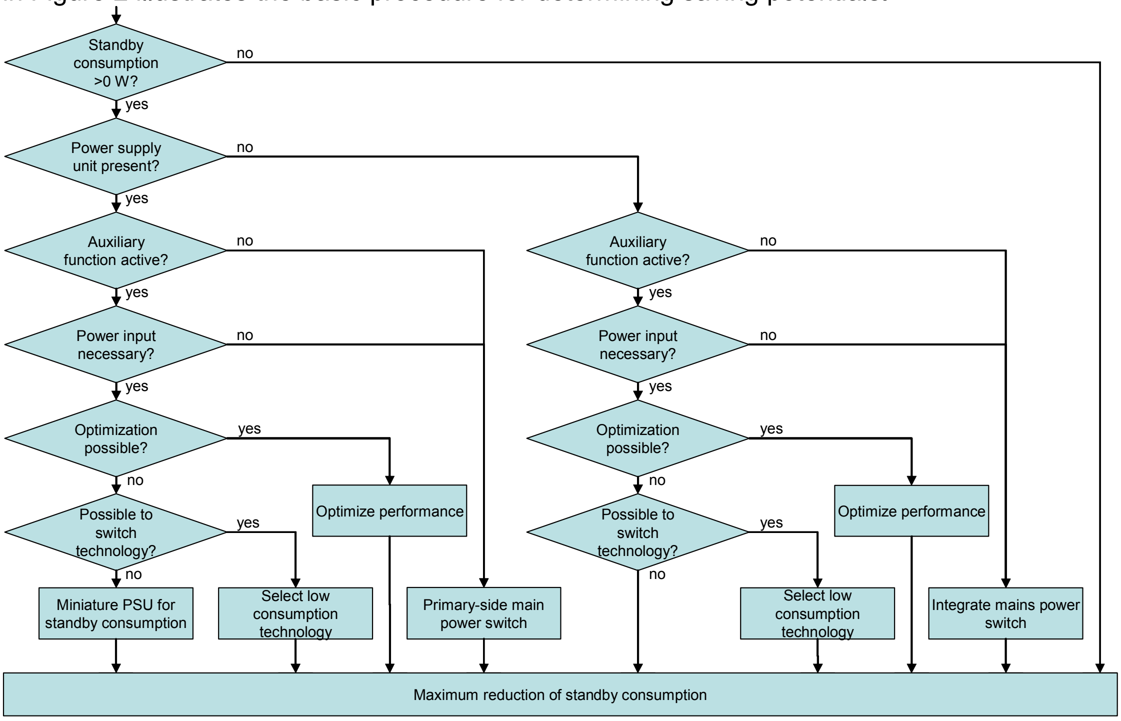

Figure 2. Decision tree to reduce the standby consumption of office appliances

For appliances with PSUs, off-mode consumption is caused by the continued operation of the power supply unit if this is not disconnected from the mains by the appliance's off-switch. The power switch disconnects the appliance on the secondary side from the mains. The primary side has a constant power demand so that PSU losses take place. In order to reduce this standby consumption, first it should be examined whether necessary auxiliary functions have power input on the secondary-side. If this is not the case, the PSU could be disconnected from the mains on the primary-side and standby consumption would thus be eradicated. The energy supply of auxiliary functions which may be one reason for power consumption could also be achieved using batteries, storage batteries or so-called supercapacitors. On top of this there are storage units available today which do not lose stored data even without a constant energy supply (EEPROM). If the measures presented cannot be implemented, energy optimization would still be possible by breaking down the PSU into a miniature PSU. However, the extra effort and energy required here for production would have to be calculated. Only a few appliances can manage without an internal or external PSU. In such appliances an unwanted power consumption of the main function of the appliance occurs if there are no auxiliary functions present or power input is not necessary to execute these auxiliary functions, but standby consumption occurs nevertheless. This can be avoided by integrating a mains power switch. If no auxiliary functions have to be powered, the off-mode can be completely avoided by integrating a primary-side power switch. For external PSUs, integrating a switch seems impracticable simply for reasons of size. As far as the user is concerned, this consumption can be prevented either by pulling the plug or using a switchable power outlet.

If a function is performed in standby, the mains on/off switch is only rarely an adequate solution. To guarantee the energy supply, the use of switchable power supplies instead of block and toroidal core transformers is the most important option for tapping the energy saving potential. Energy transformation is relevant in standby mode for processes involving heating up and maintaining a constant temperature. In coffee machines, for example, the warming plate would no longer be needed if thermal flasks were used to keep the coffee hot; in espresso machines, the additional luxury function of pre-warming the cups should be able to be switched off. For printers, copiers etc., advanced technologies make pre-warming superfluous. Considerable energy saving potentials can be achieved in control electronics thanks to modern semiconductor switches. In signal processing, maintaining data storage and reception and transmission setups are relevant for energy consumption in standby mode. Due to new storage procedures and media it is possible to reduce the energy consumption for permanent storage and storing data in the off-mode to zero. Information visualization appears in almost all appliances in various forms as part of the communication interface between appliance and user. Doing without this function to the maximum extent possible would bring about a reduction in the power consumption, but functions in standby and normal mode are frequently shown using displays. A power reduction could still be achieved using brightness-dependent dimming of the backlighting (LCD), or the display itself (LED), or turning off the backlighting or display. If a two-phase standby mode is involved, the greater degree of readiness shown by more or brighter displays and activation of sensors etc. could be triggered by pressing a switch or by approaching the device (motion detection). If the device is not switched on or no other operational activities are performed, it could return to the lower energy loss mode after, e.g. 5 minutes. Care should be taken that there is a restrained use of displays of an appropriate size and function fulfilment. Components powered by electric motors are mostly needed to fulfil the main functions of appliances. Fans and data storage devices are relevant for standby energy consumption. More efficient motors could be used in fans. The constant operation of the storage drives could be avoided by additional memory chips.

The resulting technical saving potentials for standby consumption of end-use appliances in offices are shown in Table 4. To determine these saving potentials, other factors were included apart from optimisation of the appliance-specific consumption: the development of the stock, the duration of use and the time of use of normal operation/standby modes. For the extrapolation of the feasible technical saving potential up to 2015 it must also be taken into account how many of the appliances from the stock of 2004 will have been replaced by new, optimized appliances by this time. This depends mainly on the average useful life as well as the expected market development. It is assumed here that each appliance purchased in the future has the optimized power consumption determined in standby.

Table 4. Technical saving potentials for standby consumption of end-use appliances in offices from using consumption-optimized appliances

	2010 Saving Potential		2015 Saving Potential	
	GWh	**%[1]**	**GWh**	**%[1]**
Cameras	1.6	68.7	1.7	68.7
Telephones	384.6	45.3	434.2	49.8
Computers	192.5	11.8	131.4	9.1
Monitors	109.4	16.7	112.3	16.7
Printers	247.8	36.1	215.1	31.0
Others	281.5	14.7	248.8	13.8
Total end-use appliances offices	**1 217.4**	**21.2**	**1143.5**	**20.8**

1) Referring to total electricity consumption in the BAU scenario in the respective year (see Table 2)
Source: Schlomann et al. 2005

ICT appliances in offices offer possible savings of 1.2 TWh/a in 2010. The potential remains more or less on the same level up to 2015 due to today's already foreseeable technical improvements in the reference case. Compared to the BAU scenario, standby consumption of end-use appliances in offices can be reduced by approx. 55 % through technical optimization of the appliances examined here up to 2010. In 2015, standby consumption may drop by approx. 60 % compared to the reference. This corresponds to a possible reduction of the total power consumption by about 21 % in 2010 and in 2015 respectively (Table 4). Fax machines, printers and copiers have the most obvious appliance-specific saving options. However, telephones have the biggest share in this sector because of their large numbers.

5 Conclusions and recommendations

The bottom-up-modelling of current and future electricity demand by ICT appliances in German offices brought the following main results:

- The total electricity demand for the use of end-use devices in offices in Germany amounted to 7.2 TWh in 2004 and is assumed to decrease by about 1.5 TWh up to 2010/2015 in the reference scenario. An additional consumption of 7.7 TWh is caused by the power demand of the ICT infrastructure in offices (above all for servers), for which a further growing is assumed.
- In 2004, almost half of the electricity demand of end-use appliances in offices could be assigned to the standby mode. Though the standby power consumption is assumed to decrease from 3.4 TWh in 2004 to 2.2 TWh in 2010, its share is still 38 % on average in the reference scenario.
- Compared to the reference scenario, standby consumption can be reduced by approx. 50 % through technical optimization of the office appliances examined here up to 2010 and by 60 % up to 2015.

In order to better exploit these technical energy saving potentials, a series of political instruments are available in order to promote the market diffusion of appliances with low standby consumption. In the study described here (Schlomann et al. 2005), especially the technical and legal application possibilities for a mandatory label of standby consumption were analysed. From a technical viewpoint, those appliances should be exempted from such a labelling obligation for which the application of a label is not thought to be productive. The most important reason for exemption is the existence of only a small possible technical saving potential. The biggest technical saving potentials were calculated for fax machines, copiers and printers. Another reason for exemption may be that the measurement effort required to determine standby conditions exceeds the expected benefit. This is the case for telephones without own mains supply, which are very difficult to measure. It was also examined whether to forgo a new label if other product labels are already available for the appliances like the Energy Star, Eco-Label, GEEA-Label, TCO, the German "Blue Angel". But comparing label requirements with the optimized values determined shows that often the minimum requirements remain far below the technically achievable values, so that this was . Therefore it is recommended to exempt only large household appliances, for which an obligatory EU label already exists and which, in addition, display a low saving potential in standby mode.

There are several options to design such a label, which all have their pros and their cons:

- A label indicating the standby power consumption of the appliance in Watt. The advantage of stating standby power consumption in Watt is its relatively unproblematic and precise measurability. The main disadvantage of this solution is the missing classification of the consumption for the consumer.
- This could be achieved by a standby label using the well known EU household appliance classification label which at the moment only refers to normal operation. An application of this label only to standby consumption could therefore be difficult to communicate to buyers and could give rise to confusion. Furthermore, classifying a device in comparison with other appliances would be difficult to do and would have to be continually updated.
- Another option for such a label is to refer to the idea of a 1-Watt-limit for standby consumption which has already been pursued in numerous initiatives at both national and international levels (Meier et al. 1998; www.innovationsoffensive-deutschland.de; www.action1watt.com). The appliances could be labelled as positive or negative in accordance with this 1-Watt-limit (<1 W or >1 W). Appliances which use more than one Watt in standby would be indicated with the

"negative" label; other appliances would not be labelled. In contrast, the "positive" label would pick out especially efficient appliances and the less efficient ones would not be labelled.

There are, however, other measures suited to lower standby consumption or to completely eliminate the off-mode, too.

- Voluntary agreements with manufacturers via minimum requirements and voluntary commitments are already ongoing for several kinds of appliance.
- Measures of co-operative procurement as well as information and motivation campaigns are recommended as supportive measures for an mandatory label, but are also useful without such a labelling.
- Grants and tax concessions for electricity-saving appliances are another possibility which can, however, cause high costs and "free rider" effects.
- Setting of (mandatory) minimum efficiency specifications for standby consumption of appliances.
- A general ban of the off-mode or the requirement to install a mains power switch.
- The continued use and expansion of existing voluntary labels, e. g. Energy Star, European Eco-Label, "Blue Angel" and the GEEA label.
- An obligatory declaration as an alternative to the obligatory labelling is conceivable in which the standby consumption is listed in the appliance description according to predefined criteria. This could be linked to the obligation to enter such data into a database so that up-to-date information would always be available to organisations such as the GEEA and professional buyers. This solution is supported by the proposal for a framework directive of the European Parliament and the Council to define requirements for the environmentally-compatible design of energy-using products.

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Annex 1 Energy Consumption of ICT end-use appliances in offices

Year: 2001		Energy use per appliance					
		normal operation			standby		
Main group	Appliance type	power input [W]	time of use [h/a]	consumption [kWh/a]	power input [W]	time of use [h/a]	consumption [kWh/a]
Cameras							
	Video camera/camcorder	9	15	0.1	6	30	0.2
	Digital camera	9	15	0.1	6	15	0.1
Telephone (fixed network) [1]	Cordless telephone (DECT)	3.5	330	1.2	2.5	8430	21.1
	Smart phones	4	330	1.3	2.5	8430	21.1
	Answering machines	3.5	50	0.2	3	8710	26.1
	Fax machines	55	330	18.2	12	8430	101.2
Computers							
	PC	50	1870	93.5	25	330	8.3
	Notebook	18	1430	25.7	6	770	4.6
	PDA	1.5	65	0.1	1.2	2575	3.1
Monitors							
	Cathode ray screen	80	1870	149.6	15	550	8.3
	LCD screen	22	1870	41.1	5	550	2.8
Printers							
	Ink jet	30	110	3.3	6	2200	13.2
	Laser	350	150	52.5	50	2160	108.0
	Matrix	30	440	13.2	16	3080	49.3
Other devices							
	Scanner	18	110	2.0	8	5750	46.0
	Copier	800	220	176.0	100	2090	209.0
	Beamer	180	110	19.8	7	1730	12.1
Total	**ICT end-use appliances offices**						

Year: 2004		Energy use per appliance					
		normal operation			standby		
Main group	Appliance type	power input [W]	time of use [h/a]	consumption [kWh/a]	power input [W]	time of use [h/a]	consumption [kWh/a]
Cameras							
	Video camera/camcorder	9	15	0.1	6	30	0.2
	Digital camera	9	15	0.1	6	15	0.1
Telephone (fixed network) [1]	Cordless telephone (DECT)	3.5	330	1.2	2	8430	16.9
	Smart phones	4	330	1.3	2	8430	16.9
	Answering machines	3.5	50	0.2	2.5	8710	21.8
	Fax machines	55	330	18.2	11	8430	92.7
Computers							
	PC	60	1540	92.4	15	660	9.9
	Notebook	25	1430	35.8	5	770	3.9
	PDA	1.5	110	0.2	1	2530	2.5
Monitors							
	Cathode ray screen	80	1540	123.2	15	880	13.2
	LCD screen	28	1540	43.1	2	880	1.8
Printers							
	Ink jet	30	110	3.3	6	2200	13.2
	Laser	350	150	52.5	50	2160	108.0
	Matrix	0	0	0.0	0	0	0.0
Other devices							
	Scanner	18	110	2.0	8	5750	46.0
	Copier	800	220	176.0	95	2090	198.6
	Beamer	210	165	34.7	7	1719	12.0
Total	**ICT end-use appliances offices**						

[1] Taken into account in the residential sector

power input [W]	off-mode time of use [h/a]	consumption [kWh/a]	off time of use [h/a]	total energy use [kWh/a]	Stock [in Tsd.]	Total electricity use normal mode [GWh]	standby [GWh]	off-mode [GWh]	total [GWh]
						0.4	**0.4**	**3.7**	**4.4**
1.5	871	1.3	7844	1.6	1410	0.2	0.3	1.8	2.3
1.5	873	1.3	7857	1.5	1410	0.2	0.1	1.8	2.2
						74.1	**621.0**	**0.0**	**695.1**
0	0	0.0	0	22.2	2351	2.7	49.5	0.0	52.3
0	0	0.0	0	22.4	6817	9.0	143.7	0.0	152.7
0	0	0.0	0	26.3	3174	0.6	82.9	0.0	83.5
0	0	0.0	0	119.3	3409	61.9	344.9	0.0	406.7
						1150.6	**119.1**	**309.3**	**1579.0**
4	5248	21.0	1312	122.7	10461	978.1	86.3	219.6	1284.0
4	3280	13.1	3280	43.5	6700	172.5	31.0	87.9	291.3
1	3060	3.1	3060	6.2	588	0.1	1.8	1.8	3.7
						1503.4	**84.0**	**172.9**	**1760.3**
3	5072	15.2	1268	173.1	9403	1406.7	77.6	143.1	1627.3
2.5	5072	12.7	1268	56.6	2351	96.7	6.5	29.8	133.0
						229.6	**496.6**	**83.8**	**809.9**
4	5160	20.6	1290	37.1	1763	5.8	23.3	36.4	65.5
2	5160	10.3	1290	170.8	4114	216.0	444.3	42.5	702.8
2	4192	8.4	1048	70.9	588	7.8	29.0	4.9	41.7
						1050.6	**1343.6**	**75.0**	**2469.2**
4	1312	5.2	1588	53.2	2351	4.7	108.1	12.3	125.1
2	5160	10.3	1290	395.3	5877	1034.4	1228.3	60.7	2323.3
2	1730	3.5	5190	35.4	588	11.6	7.1	2.0	20.8
						4008.8	**2664.6**	**644.7**	**7318.1**

power input [W]	off-mode time of use [h/a]	consumption [kWh/a]	off time of use [h/a]	total energy use [kWh/a]	Stock [in Tsd.]	Total electricity use normal mode [GWh]	standby [GWh]	off-mode [GWh]	total [GWh]
						0.4	**0.4**	**2.8**	**3.7**
1	871	0.9	7844	1.2	1449	0.2	0.3	1.3	1.7
1	873	0.9	7857	1.1	1811	0.2	0.2	1.6	2.0
						106.4	**724.5**	**0.0**	**830.9**
0	0	0.0	0	18.0	3622	4.2	61.1	0.0	65.3
0	0	0.0	0	18.2	7245	9.6	122.2	0.0	131.7
0	0	0.0	0	22.0	3260	0.6	71.0	0.0	71.6
0	0	0.0	0	110.9	5072	92.1	470.3	0.0	562.4
						1207.8	**135.6**	**253.5**	**1596.9**
3.5	5248	18.4	1312	120.7	10264	948.4	101.6	188.5	1238.5
2.5	3280	8.2	3280	47.8	7245	259.0	27.9	59.4	346.3
0.75	3060	2.3	3060	5.0	2415	0.4	6.1	5.5	12.1
						1197.6	**118.0**	**122.5**	**1438.1**
2	5072	10.1	1268	146.5	8453	1041.4	111.6	85.7	1238.7
2	5072	10.1	1268	55.0	3623	156.2	6.4	36.8	199.4
						259.6	**545.5**	**77.9**	**883.0**
3	5160	15.5	1290	32.0	1811	6.0	23.9	28.0	57.9
2	5160	10.3	1290	170.8	4830	253.6	521.6	49.8	825.1
0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0
						1109.3	**1324.5**	**85.4**	**2519.2**
4	1312	5.2	1588	53.2	2415	4.8	111.1	12.7	128.5
2	5160	10.3	1290	384.9	6038	1062.7	1198.8	62.3	2323.8
5	1719	8.6	5157	55.3	1208	41.9	14.5	10.4	66.8
						3881.1	**2848.5**	**542.1**	**7271.7**

Year: 2010		Energy use per appliance					
		normal operation			standby		
Main group	Appliance type	power input [W]	time of use [h/a]	consumption [kWh/a]	power input [W]	time of use [h/a]	consumption [kWh/a]
Cameras							
	Video camera/camcorder	9	15	0.1	6	30	0.2
	Digital camera	9	15	0.1	6	15	0.1
Telephone							
(fixed network) [1]	Cordless telephone (DECT)	3.5	330	1.2	2	8430	16.9
	Smart phones	4	330	1.3	2	8430	16.9
	Answering machines	3.5	50	0.2	2	8710	17.4
	Fax machines	55	330	18.2	10	8430	84.3
Computers							
	PC	70	1430	100.1	6	770	4.6
	Notebook	30	1430	42.9	3	770	2.3
	PDA	1.5	220	0.3	0.8	2420	1.9
Monitors							
	Cathode ray screen	0	0	0.0	0	0	0.0
	LCD screen	30	1430	42.9	1.5	990	1.5
Printers							
	Ink jet	30	110	3.3	4	2200	8.8
	Laser	350	150	52.5	30	2160	64.8
	Matrix	0	0	0.0	0	0	0.0
Other devices							
	Scanner	18	110	2.0	5	5750	28.8
	Copier	800	220	176.0	40	2090	83.6
	Beamer	220	220	48.4	6	1708	10.2
Total	**ICT end-use appliances offices**						

Year: 2015		Energy use per appliance					
		normal operation			standby		
Main group	Appliance type	power input [W]	time of use [h/a]	consumption [kWh/a]	power input [W]	time of use [h/a]	consumption [kWh/a]
Cameras							
	Video camera/camcorder	9	15	0.1	6	30	0.2
	Digital camera	9	15	0.1	6	15	0.1
Telephone							
(fixed network) [1]	Cordless telephone (DECT)	3.5	330	1.2	2	8430	16.9
	Smart phones	4	330	1.3	2	8430	16.9
	Answering machines	3.5	50	0.2	2	8710	17.4
	Fax machines	55	330	18.2	10	8430	84.3
Computers							
	PC	60	1430	85.8	5	770	3.9
	Notebook	30	1430	42.9	2.5	770	1.9
	PDA	1.5	220	0.3	0.8	2420	1.9
Monitors							
	Cathode ray screen	0	0	0.0	0	0	0.0
	LCD screen	30	1430	42.9	1.5	990	1.5
Printers							
	Ink jet	30	110	3.3	2	2200	4.4
	Laser	350	150	52.5	20	2160	43.2
	Matrix	0	0	0.0	0	0	0.0
Other devices							
	Scanner	18	110	2.0	5	5750	28.8
	Copier	800	220	176.0	25	2090	52.3
	Beamer	220	220	48.4	5	1708	8.5
Total	**ICT end-use appliances offices**						

[1] Taken into account in the residential sector.

power input [W]	off-mode time of use [h/a]	consumption [kWh/a]	off time of use [h/a]	total energy use [kWh/a]	Stock [in Tsd.]	Total electricity use normal mode [GWh]	standby [GWh]	off-mode [GWh]	**total** [GWh]
						0.5	**0.4**	**1.5**	**2.4**
0.5	871	0.4	7844	0.8	1513	0.2	0.3	0.7	1.1
0.5	873	0.4	7857	0.7	1892	0.3	0.2	0.8	1.3
						115.2	**733.4**	**0.0**	**848.5**
0	0	0.0	0	18.0	5045	5.8	85.1	0.0	90.9
0	0	0.0	0	18.2	7819	10.3	131.8	0.0	142.1
0	0	0.0	0	17.6	3405	0.6	59.3	0.0	59.9
0	0	0.0	0	102.5	5423	98.4	457.2	0.0	555.6
						1390.4	**76.8**	**157.1**	**1624.2**
2	5248	10.5	1312	115.2	10090	1010.0	46.6	105.9	1162.5
1.5	3280	4.9	3280	50.1	8828	378.7	20.4	43.4	442.5
0.5	3060	1.5	3060	3.8	5045	1.7	9.8	7.7	19.2
						541.1	**18.7**	**96.0**	**655.7**
0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0
1.5	5072	7.6	1268	52.0	12612	541.1	18.7	96.0	655.7
						271.1	**343.6**	**71.6**	**686.3**
2	5160	10.3	1290	22.4	1892	6.2	16.6	19.5	42.4
2	5160	10.3	1290	127.6	5045	264.9	326.9	52.1	643.8
0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0
						1206.4	**619.1**	**84.5**	**1910.0**
1	1312	1.3	1588	32.0	2522	5.0	72.5	3.3	80.8
2	5160	10.3	1290	269.9	6306	1109.9	527.2	65.1	1702.1
5	1708	8.5	5124	67.2	1892	91.6	19.4	16.2	127.1
						3524.6	**1792.0**	**410.6**	**5727.2**

power input [W]	off-mode time of use [h/a]	consumption [kWh/a]	off time of use [h/a]	total energy use [kWh/a]	Stock [in Tsd.]	Total electricity use normal mode [GWh]	standby [GWh]	off-mode [GWh]	**total** [GWh]
						0.5	**0.5**	**1.5**	**2.5**
0.5	871	0.4	7844	0.8	1554	0.2	0.3	0.7	1.2
0.5	873	0.4	7857	0.7	1943	0.3	0.2	0.8	1.3
						118.3	**753.1**	**0.0**	**871.4**
0	0	0.0	0	18.0	5180	6.0	87.3	0.0	93.3
0	0	0.0	0	18.2	8029	10.6	135.4	0.0	146.0
0	0	0.0	0	17.6	3497	0.6	60.9	0.0	61.5
0	0	0.0	0	102.5	5569	101.1	469.5	0.0	570.5
						1279.5	**67.4**	**92.0**	**1438.9**
1	5248	5.2	1312	94.9	10360	888.9	39.9	54.4	983.1
1	3280	3.3	3280	48.1	9065	388.9	17.5	29.7	436.1
0.5	3060	1.5	3060	3.8	5180	1.7	10.0	7.9	19.7
						555.6	**19.2**	**98.5**	**673.3**
0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0
1.5	5072	7.6	1268	52.0	12950	555.6	19.2	98.5	673.3
						342.1	**282.6**	**70.2**	**694.8**
1	5160	5.2	1290	12.9	648	2.1	2.9	3.3	8.3
2	5160	10.3	1290	106.0	6475	339.9	279.7	66.8	686.5
0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0
						1270.1	**434.9**	**92.3**	**1797.3**
1	1312	1.3	1588	32.0	2590	5.1	74.5	3.4	83.0
2	5160	10.3	1290	238.6	6475	1139.6	338.3	66.8	1544.7
5	1708	8.5	5124	65.5	2590	125.4	22.1	22.1	169.6
						3565.9	**1557.6**	**354.6**	**5478.1**

[1] Taken into account in the residential sector

building
performance
congress

Helping Europe to Make the Switch to Energy Efficient Lighting in Commercial buildings

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Abstract

Mitigating the impact of human activity on the environment and especially the climate is currently one of the EU's greatest challenges. With human energy dependent activity expected to rise significantly in the next 50 years, as well as looking at ways to improve the way we produce energy, the EU must get serious about changing the way in which we consume energy, particularly in buildings.

Energy efficient lighting technology[i] has the potential to offer a rapid and effective contribution to solving Europe's current energy efficiency challenge, promising significant savings in CO_2 in a cost effective and practical way. For the commercial building sector, where energy saving, functionality and cost are key priorities, significant "wins" can be achieved. Energy efficiency is now seen as a social and commercial obligation and not a choice, a number of recent legislative developments have highlighted this.

As the representative of companies manufacturing 95% of all European–produced lamps, the ELC[ii] is actively promoting a range of legislative and voluntary measures in Brussels and at national level to improve energy efficiency through increased take-up of energy efficient lamps in the EU. Our objective: to help Europe to make the switch.

The ELC - Helping Europe to Make the Switch to Energy Efficient Lighting in Commercial buildings

According to the European Commission by 2010 about 180 million tonnes of carbon dioxide[iii] could be prevented with new and **energy-efficient appliances** alone in Europe. Inefficient **lighting technology** - a basic commodity for the commercial building sector - is a major contributor, producing tons of energy and unnecessary CO_2 each year.

New energy efficient lamps can **reduce energy consumption by as much as 80%** and can **last between 5 and 30 times longer** than conventional equivalents. The diagram below illustrates the potential end-use savings of a range of energy using products by 2030:

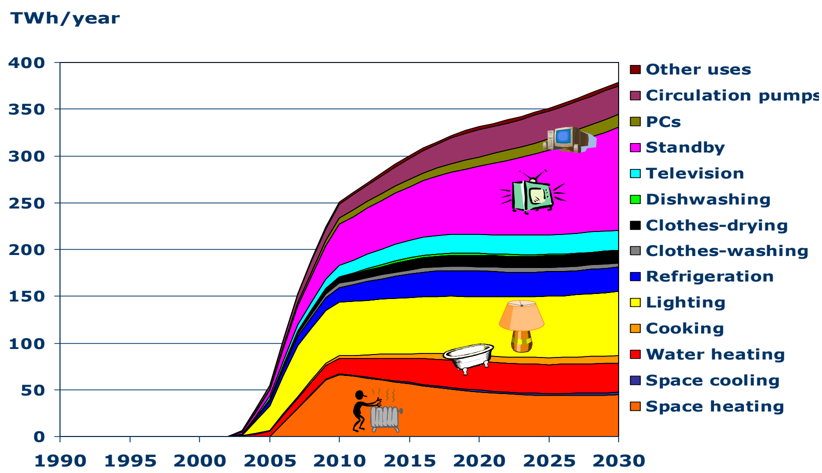

Image 1 - Source: International Energy Agency 2005

Helping Europe to Make the Switch to Energy Efficient Lighting in Commercial buildings

According to the Eurobarometer's latest special report "Attitudes towards Energy"[iv], issued on 24th January 2006, only 43% of EU citizens think about energy consumption when purchasing lamps and this figure does not represent the percentage of the 43% who actually BUY and INSTALL energy efficient lamps. This trend is equally true for the commercial sector and with office lighting accounting for a large total of the EU's commercial building stock's energy consumption and costs, the potential for improvement in this area are significant.

As the representative of companies manufacturing 95% of all European–produced lamps, the ELC[v] does not take its own responsibility lightly. For the past two years ELC members have worked closely with the European Institutions, national governments and others from the lighting value chain to actively promote a range of measures in Brussels and at national level to improve energy efficiency through increased take-up of energy efficient lamps in the EU.

The approach is three fold:

1. Working with legislators and industry to restrict the supply of the least energy efficient products to the European market where numerous energy efficient equivalents already exist.
2. Helping to stimulate the demand for energy efficient products and services through improved communication and more and better targeted financial incentives.
3. Communicating the benefits of energy efficient lighting technology.

1. Restricting the supply of inefficient lighting technology on the European market

Lighting is one of the few markets where although a great deal of new technology exists; old technology is still being used. To reduce the problems associated with old and energy inefficient products on the European market, a combination of specific measures to dissuade consumers from purchasing them may be necessary. For example a **restriction on the marketing of the least energy-efficient lamps** in Europe where alternatives exist which satisfy customer performance demands and other economic considerations. For example, for Standard Phosphor lamps, used in offices, 3-band (more efficient) fluorescent lamps should be used to replace them giving higher light output.

Achieving a shift to energy efficient alternatives in these areas would go a long way to achieving the CO2 reduction potential identified by the Commission – and in a targeted, **cost-efficient** and highly effective way[vi].

Under the **Energy Using Products Directive (EUP)**, office lighting products will be subject to a specific implementing measure (in as early as 2008), and the lamp industry and its value chain are working with the Commission to target products that are the least efficient in terms of eco-design and energy consumption and offer the greatest potential for CO_2 reduction. For many commercial buildings, particularly in Central and Eastern Europe, where inefficient Standard Phosphor lamps are still widely used, this legislation will have a great deal of impact.

To help the European Commission and its consultants to identify which products are least energy efficient (and might warrant restrictions) or which are most energy efficient (and might warrant inclusion in positive discriminating labeling or procurement schemes), the ELC has been developing its own **eco-profiles** for its products.

In conjunction with the EUP Directive a further way to ensure a high impact and cost-effect market shift would be to strengthen the **CE Label to provide information about energy efficiency of products**. The ELC is working to encourage its extension to cover ALL lamp types in particular lamps for professional applications (e.g. street lighting and offices and industry).

2. Stimulating the demand for energy efficient products and services

A key obstacle to a proper market reaction to energy efficient lamps with a low **total cost of ownership**[vii] is often a higher purchase price coupled with lack of consumer understanding of the overall long term benefits. Although the purchase price is higher than conventional less energy efficient lamps, the total cost of ownership is significantly lower as the lamp is replaced less frequently and uses less energy, with a consequently lower cost for electricity consumption. Two recent legislative developments in particular aim to stimulate the market for energy efficient products in the commercial building sector. The ELC is working to ensure that theses initiatives are implemented effectively

Under the European Commission's **Directive on the promotion of end-use efficiency and energy services (ESD)**, member states are now required to establish national energy efficiency action plans and much of the emphasis will be on energy saving in the building sector.

Bottlenecks presently prevent these efficiencies from being captured, and even though many in the building sector appreciate that the total cost of ownership of energy efficient technology is significantly lower, making this happen in practice is still a major challenge. Several of the barriers; lack of available financial resources, a lack of understanding of appropriate and available incentives and little experience also hampers real progress in this area, particularly in the EU's newer and future member states.

The ELC is working with national governments to ensure that action plans under the ESD are supported by structures and bodies – such as the UK approach including its ***Carbon Trust***[viii] - a national energy agency for professional applications. The establishment of such bodies throughout the rest of the EU is important to help stimulate the uptake of energy efficient technologies in practice. The approach is also useful in the way that it helps to overcome the problems of market surveillance[ix] in the lighting sector as well as maintaining information campaigns on energy efficiency to best effect.

Under the **Energy Performance of Buildings Directive**, from 2006 all large public buildings in the EU are required to become more efficient and issue energy efficiency certificates. One of the main barriers to improving energy efficiency in public buildings is the initial investment hurdle. The ELC is working at a number of levels to help end users identify mechanisms to overcome these hurdles through:

- ***Helping accelerate the market for energy services.***

The ESD Directive seeks to increase energy efficiency all along the supply chain as far as the retail stage when energy is sold to the end-user. It hopes to do this by making energy services an integral part of the internal market for energy and encouraging the developments of organisations like Energy Service Companies (ESCOs) at national and local level. However in several EU countries these structures are yet to exist or are not yet developed, ELC is working to encourage the sharing of best practice more effectively.

- ***Promoting and encouraging the use of European and national financial incentives***

Tax concessions and incentives, low interest loans and free energy audits, green investment banks etc can enable end-users to bridge the initial investment hurdle for energy efficient lighting systems. Often theses structures do not exist and where they do, application procedures are currently too burdensome, particularly for SMEs.

- ***Promoting and encouraging Green energy Procurement***

The EU's current public procurement measures, although already a step in the right direction, are unfortunately not enough to encourage proper market reaction in most cases. The ELC is actively working to encourage and educate about green procurement and the environmental and cost benefits of procuring energy efficient lighting technology.

In May 2006, along with other prominent actors from NGOs, public authorities and the lighting value chain, the ELC will lead the **BUY BRIGHT** initiative, a best Practice Platform for Public Sector Energy Efficient Lighting. This project funded under the SAVE field of 'Intelligent Energy Europe Programme

(Type 3 actions), will initiate a process to ensure a tailored exchange of experiences looking at practical and workable solutions to help public purchasers and procurement officers make the RIGHT purchasing decisions and be BRIGHT in investments that concern lighting.

Do you buy BRIGHT? http://www.elcfed.org/content.php?level1=14&mode=1

In January 2006, the ELC also submitted an application for another innovative pilot project to encourage green procurement. If successful, **Bottom Up to Kyoto** (**BUtK**)", will give municipalities from Europe's newer and future member states a helping hand to overcome the barriers to switching to energy efficient lighting technologies.
The ELC is also working to encourage a phase in of **minimal energy efficiency requirements** in all national and European public procurement contracts by 2020 - notably for street lighting and public buildings – as the current 'guidelines' are insufficient.

3. Communicating the benefits of energy efficient lighting technology.

Even though the environmental benefits of energy efficient lamps are considerable, end users need to understand them and also see the economic benefit – this is particularly true in the commercial building sector where purchase price and functional and aesthetic performance often take precedence over environmental concerns. As such communication needs to centre on the benefits – i.e. **cost savings and improved light quality.**

The most effective campaigns also offer access to incentives – discounts, free advice etc, as such support a range of stakeholders (governments, financial institutions, lighting manufacturers, the distribution chain including wholesalers, installers and end-users) from national and European level is therefore key.
Most facilities managers, building managers or financial officers belong to and rely on professional organisations for new ideas and dependable advice. The ELC has also encouraged the European Community to look into financial support for **energy efficiency training programmes** at national level for professionals responsible for lighting and purchasing. These programmes should be executed by professional bodies in conjunction with technical energy experts such as lighting technicians for the lamp industry. Furthermore, energy efficiency courses should be included as part of professional development programmes for purchasers.

The ELC has and continues to work actively all of the initiatives above. For further information see: www.elcfed.org/content.php?level1=4&mode=1

References

[i] For more information on energy efficient lighting technology see www.elcfed.org
[ii] The members of ELC are Aura, GE, LEUCI, NARVA, OSRAM, Philips and Sylvania. These companies employ 50,000 people in Europe and account for 5 billion Euro European turnover.
[iii] Around half of the EU's commitment under Kyoto
[iv] http://europa.eu.int/comm/public_opinion/index_en.htm
[v] The members of ELC are Aura, GE, LEUCI, NARVA, OSRAM, Philips and Sylvania. These companies employ 50,000 people in Europe and account for 5 billion Euro European turnover.
[vi] Figures show that if all energy inefficient lighting in Europe were upgraded to the latest technology solutions – for domestic, public and private sectors, the annual running cost savings would be in the **region of 4.3 billion euros equivalent to CO_2 savings of 28 million tons per year.**
[vii] The total cost of ownership of a product represents the cost incurred throughout its life cycle. For energy efficient lamps, although the consumer purchase price is higher than conventional less energy efficient lamps, the total cost of ownership is significantly lower as the lamp is replaced less frequently and uses less energy, with a consequently lower cost for electricity consumption for the consumer
[viii] www.thecarbontrust.co.uk
[ix] For more information see the ELC's See ELC 'Did You Know about the Problems of Poor Market Surveillance of the European Lamp Market?'

building
performance
congress

Commercial building lighting energy use: an in-depth global assessment of lighting service, energy consumption, savings and potentials

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Abstract
Lighting is the single largest source of electricity consumption in commercial buildings. Globally it accounts for 1133 TWh each year; equivalent to 50% of the output of the worlds' nuclear power plants. This electricity costs end-users US$88 billion and makes up 60% of the total annual lighting bill of US$150 billion (including equipment and labour costs). On average, commercial buildings spend US$4.5 per square metre of floor area on lighting each year, but this figure varies considerably by region and commercial building type. It is estimated that existing lighting energy efficiency policies for commercial buildings including building codes, minimum energy performance standards for lamps and control gear and market-transformation programmes are saving 220 TWh per annum globally and will go on to save 445 TWh in 2030 even if they are not strengthened in the future. This amounts to 30% of global commercial building lighting consumption in 2030 and will not only save end-users US$66 billion in total lighting costs but will avoid 260 Mt of CO_2 emissions at a negative net cost of US$–254 per tonne. However, there are large uncertainties in this assessment, not least because insufficient information is available regarding the level of compliance with existing policy requirements. The sparse data that are available suggest that current compliance with building code provisions for lighting is poor and, consequently, a large amount of cost-effective energy savings is being squandered.

Important as savings from existing policies appear to be, they are small compared to the cost-effective savings potentials that remain to be realised. Were only lighting systems that minimised life-cycle costs to be installed in commercial buildings from 2008 onwards, it is estimated that their lighting consumption in 2030 would be 45% lower. These savings come from a mixture of using more efficient light sources, control gear and luminaires as well as better lighting controls, such as presence sensors and automatic daylight sensing and dimming.

This paper reports details of the findings summarised above, which are taken from a new in-depth analysis of global lighting by the International Energy Agency and published in the book *Light's Labour's Lost*. The quantitative analysis is produced using a disaggregated bottom-up model that treats lighting energy use in each end-user sector for seven world regions. Details of the model, its method and input data and results are discussed. Policy implications are discussed in a companion paper.

1. The IEA's assessment of commercial[1] lighting around the world
There are few recent analyses of the breakdown of energy consumption in the commercial sector. A CADDET report (1995) estimated that lighting represented 45 % of electricity consumption in commercial buildings, followed by 34 % for office equipment, 7 % for ventilation and pumping, 6 % for air conditioning, 5 % for domestic use and 2 % for humidification. Mills (2002) estimated that lighting in the commercial sector consumed 968 TWh of electricity globally in 1997; some 48% of a world electric lighting total of 2016 TWh. That analysis, conducted for the IEA, was based on a compilation of estimates for 38 countries representing approximately 63% of the world's population. However, there are many reasons to wish to revaluate these figures. The data used is now out of date and in some cases has been surpassed by more reliable figures. For example, two figures were used for commercial lighting energy use in the USA of 246 TWh and 340 TWh based on Vorsatz *et al* (1997)

[1] In this paper the term "commercial" refers to all activities in the service sector and includes public buildings

and Energy Information Administration estimates, also reported in Vorsatz *et al*, respectively. Since that time a more reliable study has been conducted, the US Lighting Market Characterisation Study (Navigant 2002) reports values based on a sophisticated marriage of the findings of almost 25000 utility lighting audits and the national commercial building energy consumption survey of 5430 national representative buildings. This found that US commercial buildings consumed 391 TWh of electricity for lighting in the year 2001. Second, there has been exceptionally strong economic growth in some countries since that time, most notably in China and this is likely to significantly alter the total. Third, the quality of data reported in most countries cited in the review is highly debatable and in many others was non-existent. Given this it the IEA conceived the need to derive new estimates based upon an alternative methodological approach, as outlined below.

The new IEA analytical methodology

The approach adopted in the new IEA analysis is to use all available data to independently simulate lighting demand and supply in order to characterise the total installed lighting systems and estimate its energy use. Lighting demand is analysed via a purpose built bottom-up model that divides the world into seven regions: IEA North America, OECD Europe, Japan+Korea, Australia+New Zealand, the Former Soviet Union, China and the Rest of the World. For the commercial sector the building stock is divided into seven broad categories: offices, educational buildings, healthcare, retail, hotels and motels, warehousing and others. The total floor area of each commercial building type was further sub-divided into space functions with common lighting characteristics e.g. offices, corridors, toilet blocks, reception areas, storage/utility areas, etc. In each of these areas the default assumption is that the lighting system is designed to provide delivered light levels that match illumination requirements specified in national recommendations or regulations. This is then converted into default lighting power density levels (W/m^2) once the relative mix of lamp, luminaire and room coefficient of utilisation[2] (CU) values are known, or can be derived using the method described below. The lighting power density levels are subsequently converted into energy consumption figures if the hours of usage and lighting control characteristics are known.

Default assumptions on LOR and CU

In order to estimate average luminaire and room losses the IEA analysis took the highly detailed data available in the US Lighting Market Characterisation Study (Navigant 2002) as its starting point. This gave information on the precise mix of lamps per type of space function in the US commercial building sector of 2001. By applying the information on lighting usage and energy intensity (expressed in units of kWh/m^2) it is possible to determine the relative source lumen losses due to luminaire losses (LOR) and room losses (CU) for the US commercial building stock. In the event that no other regionally specific data is available the US values are assumed to be indicative of the typical losses incurred in commercial buildings in other regions.

Deriving the lamp mix and hours of use

Simultaneously to the above, national data was gathered on typical lighting operating hours by building type, and on sales by each of twelve major lamp types: linear fluorescent lamps (T5s, T8s (differentiated by halo- and tri-phosphor types) and T12s), incandescent lamps (halogen spot lights, incandescent reflector lamps and standard incandescent GLS lamps), high intensity discharge lamps (high pressure sodium, mercury vapour and metal halide lamps), compact fluorescent lamps (ballast integrated and non-integrated varieties), and LEDs (Light Emitting Diodes). Sales data was also gathered on ballasts by efficiency level. From this data, including known divisions of lamp and ballast sales by lighting sector and known lamp and ballast lifetime characteristics, it was possible to apply a lamp replacement stock model to estimate numbers of lamps and ballasts in the commercial building sector by type. If reliable data was also available characterising the installed lamp base and use in the commercial sector for any given country, as in the USA for example, this was used to prime the model. If such data was partially available, but was not very consistent or reliable, as in Europe – see discussion below, this was also used to help prime the model. Otherwise, the lamp sales data was used in isolation to derive shares of lamp type by space function.

[2] The proportion of light emitted by luminaires that provides useful illumination

Once the generic lamp mix for the entire sector was known the US Lighting Market Characterisation Study data was used to derive the relative distribution of lamp types by space function e.g. if in the US commercial sector linear fluorescent lamps provided ten times as much light in offices as incandescent lamps this ratio was initially assumed for other regions but then adjusted for the relative amount of light provided by linear fluorescent lamps and incandescent lamps in the two regions. This approach takes account of how lamp types are used in practice and respects the type of allocation of lamps by space type most commonly found. Similarly data and estimates are often available on the annual average hours of use of lighting in different building types and regions but they may not be available by space function. In this case the average value is made to respect the local data but the relative values by space function are adjusted to match the US data.

Calibrating between data sources
The process outlined above allows all available data sources to be used to estimate lighting installed power levels and full time equivalent hours of use, based on the factors that influence lighting supply and demand. The resulting calculations are then used to produce estimates of total lighting energy consumption. In the case of the USA they explicitly match the Navigant (2002) values for 2001 because they reconstruct the same data sources used in that study. By so doing, however, they establish that for the Navigant data to be correct the combined luminaire and room losses collectively add up to losses of about 75% of source lumens i.e. that on average about 1 in 4 lumens emitted by lamps used in US commercial buildings was providing a useful visual service in 2001.

For other regions, the consistency of the estimates they produce depends on the consistency of the supply and demand side data sources available. If there are well respected and credible national estimates of commercial building lighting energy consumption the loss functions in the model are adjusted to be consistent with those. However, if the modelling process establishes that the national or regional lighting supply and demand side data are inconsistent an attempt is made to reconcile the data based on a judgement of its credibility. When little supply or demand data is available[3] defaults are used based on international values and some interpretation of local circumstances e.g. for the rest of the world region it was not necessarily assumed that installed illumination matches CIE recommended values when this is known to not be the case in many localities.

2. Summary of global commercial lighting energy use

From the process outlined above it is estimated that 1133 TWh of final electricity was consumed by commercial lighting globally in 2005, Figure 1. This amounts to about 43% of total lighting electricity consumption and just over 30% of total electricity consumption in the commercial sector. The lighting systems using this energy produced an estimated 59.5 P-lm-hrs of light at an average source-lumen efficacy of 52.5 lm/W. This is two and a half times greater than for residential lighting, but not as high as for outdoor stationary lighting. Commercial lighting is thus the most important lighting end-use in terms of energy use and light output and is of intermediate efficiency compared with the other sectors.

As already alluded to a very significant proportion of the source lumens[4] serve no useful purpose because of: absorption in luminaries (expressed through the LOR[5]), room losses (expressed through the coefficient of utilization) and delivery of light to either empty spaces, or spaces where there is already adequate daylight. Unfortunately, these loss factors can not be easily quantified because there is a lack of statistically representative data; however, it is clear that only a small proportion of source lumens make a useful contribution to overall illumination in the commercial sector; albeit that the CU and LOR values are generally significantly higher than in the residential sector.

[3] The seven regions with the geographical coverage they have largely because data is available within these groupings. The greatest assumptions have been made for the rest of the world region.
[4] The quantity of light emitted by lamps as opposed to that emitted from luminaries (the lamp and its housing)
[5] Luminaire Output Ratio, which indicates the share of source lumens which exit the luminaire

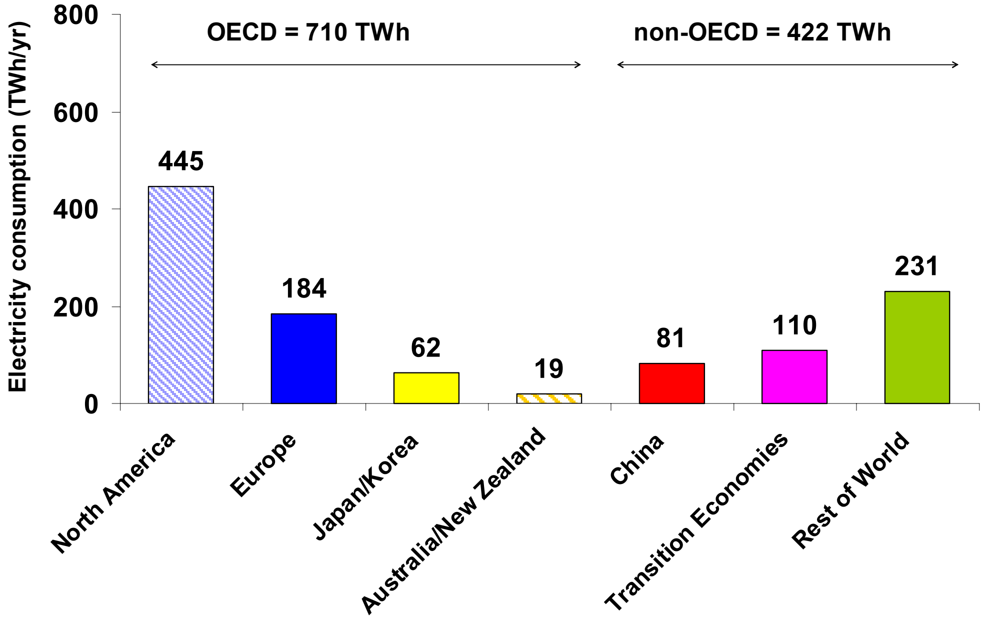

Figure 1. Estimated commercial building lighting energy consumption in 2005

The requirement for lighting and the total lighting energy consumption varies from one type of building to another, in part because of different occupancy patterns. For example, buildings which operate 24 hours per day, 7 days per week, such as hospitals, some shopping centres and hotels, have much higher lighting energy demands. The largest users are retail, offices, warehousing and educational services, which collectively account for 70% of commercial lighting energy use.

Lighting energy intensity also shows important variation depending on the building type. The estimated global average lighting intensity in 2005 was 32.5 kWh/m^2 per year, but this varies from a low of 25.2 kWh/m^2 for educational buildings to a high of 46.7 kWh/m^2 for healthcare buildings, Figure 2. These results illustrate the importance that occupancy levels have on building lighting energy consumption.

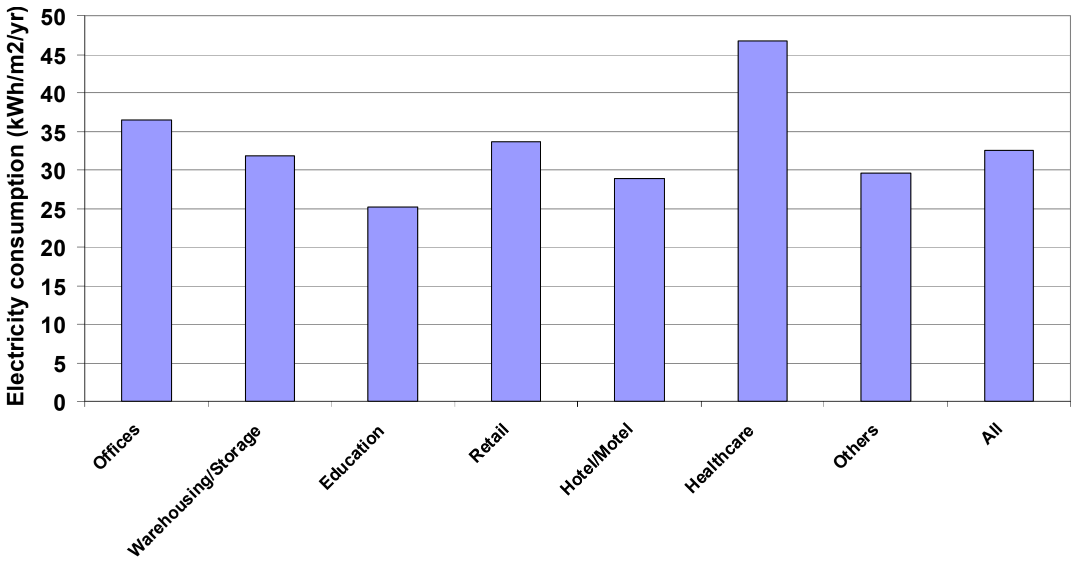

Figure 2. Estimated global average lighting energy intensity by building type in 2005

The commercial sector demonstrates a different pattern of usage of lights. While incandescent bulbs are popular, they are much less so than in the residential sector. Fluorescent lights are much more common in offices, retail outlets, schools and other facilities where there are wide open spaces for work or shopping. CFLs are also gaining market share and in 1998 some 301 million CFLS were sold for commercial use in Western Europe, 262 million in North America and 109 million CFLs in Japan. Since that time CFL sales have grown although the share going to the commercial sector is falling. The estimated share of light emitted by each source in 2005 in the commercial sector is shown in Figure 3 for the world and for each modelled region. While there is considerable similarity in the mix of commercial sector illumination provided by light source in many regions, the differences are sufficient enough to give rise to the variations in average efficacy that are discussed below.

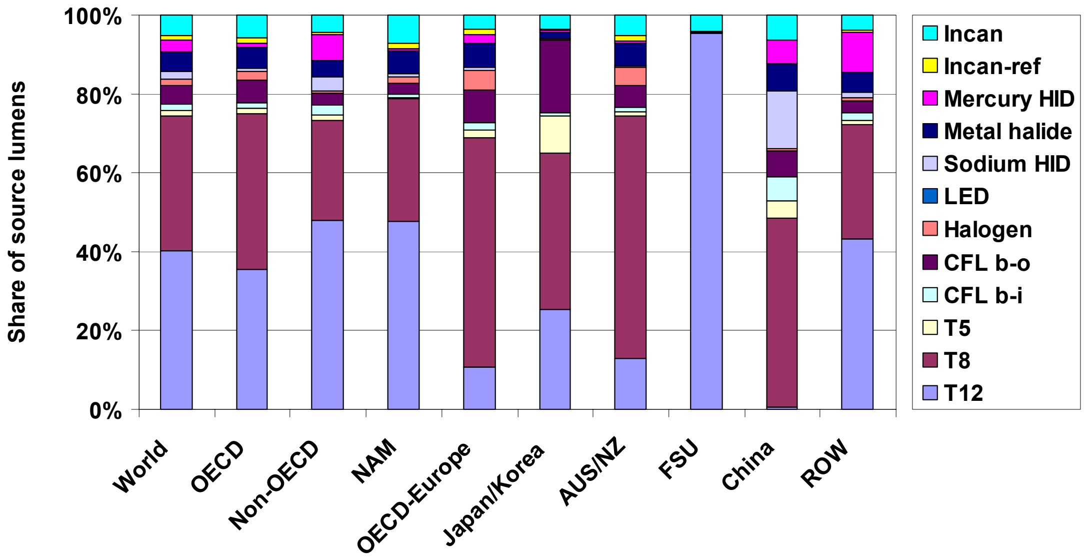

Figure 3. Estimated share of light output by source in the commercial buildings sector of 2005 by region (Total = 59.5 P-lm-hrs)

3. Results by region

Table 1 shows the findings of a survey of lighting in 1583 commercial buildings in California. The average installed lighting circuit power (lighting power density or LPD) is 15.8 W/m^2 but this varies from a low of W/m^2 10.8 for warehouses to a high of 22.8 W/m^2 for restaurants.

Table 1. Lighting characteristics of commercial buildings from a survey in California 1995 (Post-treatment of CEUS database reported in Herschong Mahone Group (1999))

Building Type	Number of premises	Total area (1000 m^2)	Daily operating hours FTE	Average efficacy (Lm/W)	Lighting Power Densities (Watts/ m^2) Average	Lower 90th	Upper 90th	Illuminance (Lux)	Were efficacy= 85lm/W
Small office	344	468	7.6	56	15.8	14.6	16.9	886	10.4
Large office	100	1752	9.7	54	16.1	13.8	18.5	872	10.3
Restaurant	198	77	12.3	41	22.6	16.4	28.7	915	14.1
Retail	339	959	9.3	50	15.1	12.6	17.5	753	8.9
Grocery	104	148	17.3	60	18.4	17.0	19.8	1104	13.0
Warehouse	114	596	7.4	59	10.8	8.2	13.5	629	7.4
School	33	150	6.6	61	17.4	15.4	19.5	1063	12.5
Health	102	278	7.6	51	16.5	12.4	20.6	840	9.9
Lodging	30	262	18.0	26	17.8	14.6	20.9	453	7.0
Misc.	219	365	8.3	46	18.9	14.1	23.8	871	10.2
Total	1583	5055	9.5	52	15.8	13.1	18.7	819	9.5

Average efficacy is 52 lm/W and ranges from a low of 25 lm/W for lodgings to 61 lm/W for schools. There is a pronounced spread in the distribution of installed lighting power densities within each building class. The buildings in the upper 90th percentile use 19% more power per unit area than the average and 43% more than those in the lower 90th percentile.

This data, although a decade old, reveals myriad routes by which a substantial amount of lighting energy could be saved that are typical of this sector in the OECD. First, using more efficient lamps and control gear to raise the overall efficacy to 85 lm/W would cut the average installed power density to just 9.5 W/ m^2; a saving of 39% (see the last column in Table 1). The most efficient fluorescent lighting systems can attain 95 to 100 lm/W, so this is far from an impractical target. Second, at a floor-area weighted average level of 819 lux the installed illuminance in the California sample appears to be appreciably greater than the current IESNA recommended values (about twice as high). Lowering the values to match the IESNA values would save about 50% of the total lighting demand. Third, the number of full time equivalent operating hours average 9.5 hours per day, or some 3483 hours a year. This is the equivalent of all the lights being activated for 40% the year. Considering typical working hours and the high coincidence of working hours with daylight this figure suggests that a large proportion of lighting is left switched on when there are no occupants and that little use is being made of daylight to offset electric lighting.

Applying some rough rules of thumb to assess the savings potential from the deployment of best practice lighting to the above sample of buildings (assuming: high efficacy lighting, correct sizing to attain the recommended illuminance levels and proper lighting control) gives an estimated savings potential of 84%! The sample above had an average annual lighting energy intensity of 151 kWh/m^2 per year while the good practice case would require just 25 kWh/m^2.

The Californian building sample figures for installed lighting power appear to be fairly typical of the US as a whole and not unrepresentative of the OECD at large. Based on a synthesis of the available sources, and most notably the Navigant 2002 study, the average US commercial building had a lighting power density of 17.4 W/m^2 in 2000, while the figure for the average European commercial building was about 15.5 W/m^2. In Japan the estimated values are a little lower at about 13 W/m^2, although there is even less certainty for this value than in the previous two regions. Estimated values for Australasia are slightly greater at 16.5 W/m^2 although here again there is considerable uncertainty. The regional variation in these estimates is almost certainly within the margin of error of the available data sources and thus should be considered as indicative; however, it is based on assessments of available data. Of all the regions, the US data is comfortably the most comprehensive, but even here there are outstanding questions about the reliability of all the figures. This stresses the importance of gathering good end-use data for successful policy analysis and design.

Overall, while it appears there is a considerable homogeneity in installed lighting loads in OECD commercial buildings, at least at the aggregate level, there is great variation between otherwise similar buildings in any given sample. Figure 4 illustrates this point. It shows the normalised distribution of lighting power densities from a survey of 256 offices in California. The average value is 5% higher than the requirements set in the 2001 Title 24 state building codes for new and retrofit buildings and 20% higher than the new requirements in the October 2005 revision of the code. This is to be expected because the codes are more recent than the lighting systems in the sample of buildings surveyed. What is more revealing is the large spread between the lowest and highest values. The lowest is 16% of the average and the highest 2.4 times the average, while between the two extremes there is a 15 fold difference. Similar divergence ranges are found in such surveys around the world.

Lighting power density is a poor measure of lighting quality but lighting energy consumption is usually roughly proportional to it, thus these findings imply there is a vast difference in the energy used for lighting per unit area between different buildings with similar primary functions. However, the installed lighting power density is only one measure of the lighting system characteristics. For example, variations in delivered light levels and system efficacy can cancel each other out to produce a similar installed lighting power density. Furthermore, there appears to be significant regional variation in the average LPD observed between types of buildings.

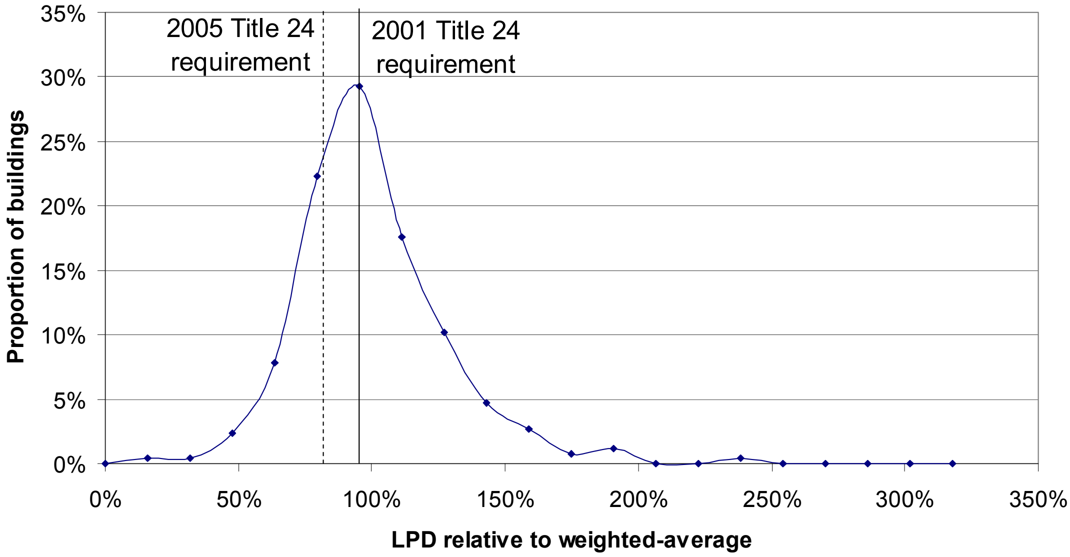

Figure 4 Normalised LPD distribution for a sample of Californian offices (Post-treatment of CEUS database reported in Herschong Mahone Group (1999))

The USA, Canada and some European countries aside, there is a dearth of good publicly available data on many of the key statistics pertaining to lighting energy use in the commercial sector. This is remarkable when one considers how much energy is used in providing this service. Regrettably, the majority of OECD countries have failed to establish and maintain reliable data sets on this topic despite the high public policy interest in economising lighting energy use. As a result a great many assumptions have to be made to try to characterise current practice and a mixture of data sources, including anecdotal ones, have been applied to make the existing estimates. With these caveats noted, the estimated average efficacy of commercial sector lighting by region is shown in Table 2 for the year 2000.

Table 2. Estimated average lighting characteristics of commercial buildings in the OECD in the year 2000

Region	Average LPD	Specific energy use	Average annual operating period FTE	Lighting system efficacy	Commercial building floor area	Total electricity cons.
	W/m^2	kWh/m^2	Hours	Lm/W	(billion m^2)	TWh/yr
Japan+Korea	12.6	33.0	2583	62.7	1.7	54.6
Australia+N.Z	16.5	31.7	1924	43.5	0.4	12.7
North America	17.4	59.4	3928	50.1	7.3	435.1
OECD Europe	15.5	27.7	1781	46.1	6.7	185.8
OECD	15.6	43.1	2867	49.6	16.1	688.2

Note: There is more data available for the North American and European regions than the others and hence greater confidence in these estimates. Data in other regions is partly based on an evaluation of lamps sales data, rather than comprehensive market characterisation studies.

Factors influencing efficacy

Interestingly, there is an almost identical share of linear fluorescent lamp (LFL) lighting by region across the OECD; however, differences in average efficacy occur because of variations in the relative use of compact fluorescent lamps (CFLs), high intensity discharge (HID) lighting and various incandescent light sources; and because of significant differences in the average efficacy of LFL technology and control gear used in the various regions. From the new IEA analysis it appears that the commercial lighting sector in Japan has the highest efficacy of all OECD regions, but this is not because of the use of particularly efficient LFLs, as there is still a high proportion of less efficient T12 lamps in use; rather, it is due to the very low usage of incandescent and halogen sources compared with other regions. The average efficacy of commercial lighting in IEA North America is lower than in Japan, but slightly above OECD Europe for rather complex reasons, that are now discussed.

LFL efficacy and ballast performance in OECD countries

With the exception of some regulations for LFL ballasts and some national building code requirements Europe has taken a rather laissez faire attitude to commercial lighting regulations thus far. The USA and Canada by contrast have introduced regulations at both the system and the lamp level that have obliged efficacy improvements in specific lighting product types. The rationale behind these regulatory stances is partly explained by the natural market development of LFLs in the two regions. Europe, most of Asia, Africa, the Middle East, Australasia and Latin America operate their electricity networks at 220-240V, 50hz, which naturally favours the adoption of T8 lamps at the expense of T12s. This is because in 220-250V, 50Hz systems T8s fit directly into older T12 fixtures and hence it is not necessary to replace the fixture when switching over to T8s. By contrast in Japan, North America and parts of Brazil lower voltage networks are in place and this is not possible; hence T8s have been much slower to replace T12s.

On face value this would imply that the stock of LFLs in the 220-240 V regions would have a higher average efficacy relative to the 120V regions; however, this has arguably led to regulatory complacency in other regards whereas the opposite has been true in the 120 V regions. US, Canadian and Japanese regulations have effectively phased out the less efficient halo-phosphor T8s from their markets so that all remaining T8s are of the more efficient tri-phosphor variety. Although use of T12s is still allowed, only the most efficient varieties can still be sold and these are only slightly less efficient than the least efficient T8s. By contrast Europe has not imposed any requirements on LFL efficacy, but has seen a natural and seamless adoption of T8 lamps because there has been no reason to continue to use T12s. The sole exception is for extra long LFL tubes where T12 lamps are the only ones available due to their greater thickness and lower risk of breakage. In consequence the share taken by T8s is much higher in Europe, Australasia and China than in the lower voltage network regions, but the average T8 efficacy is poorer than in the 120V regions because the halo-phosphor T8s predominate. Until very recently a similar situation applied in Australasia, but both Australia and New Zealand have now adopted LFL regulations of a similar ambition to those in place in North America.

Moreover, North American ballast energy performance regulations are more demanding than European regulations and as a result a very large part of the North American ballast market is taken by efficient electronic ballasts. In Europe, despite a gradual phasing in of ballast energy performance requirements that prohibit sale of the least efficient electromagnetic ballasts the intermediate and more efficient electromagnetic ballasts dominate the market and overall ballast energy performance is not as high as in North America. The net result is that overall LFL system efficacy is not quite as high in Europe as it is in North America despite T12s, which are inherently less efficient, continuing to have a significant market share in North America.

Having remarked on this it is important to understand that at least as much of the regional difference in average commercial sector efficacy is due to differences in efficacy between the quarter of commercial illumination that is not provided by LFLs in each region. Here it appears that North America and Australasia have relatively high usage of incandescent lamps, while Japan has very low usage and Europe is in between. Commercial sector CFL usage is particularly high in Japan, quite high in Europe and less so elsewhere. Halogen lamps are most common in Europe and Australasia and HID lamps are most used in North America and Europe, Figure 3. Overall, Japan has the highest average efficacy for the non-LFL part of commercial lighting, followed by Europe.

Operating hours, illuminance and energy use

Efficacy is only one factor effecting lighting energy consumption; however. The length of the total operating period and the average illuminance provided also have a major influence on the final consumption. Here the picture seems to be considerably different between OECD regions and far more so than for the other factors discussed. Ironically, the region with the shortest average operating hours, Europe (Table 2), is also the one where the weighted-average location of the population is furthest from the equator.

It is difficult to know why these differences occur but the available sources are unambiguous regarding the main characteristics of regional hours of use. Apart from the Californian data already mentioned the Navigant (2002) study found that on average US commercial buildings operated their lamps for 3614 hours per year in 2000. The CIBEUS (2002) study implies Canadian commercial buildings are operated on average for about 4380 hours per annum. A survey of Japanese offices found that the annual average hours of use for lighting was 3780 hours (ECCJ 2003). By contrast European surveys report annual hours of lighting use of between 1405 to 1901 for offices (GL 1999; ENERTECH 2005, and Kofod 2001) and for education establishments of between 1247 and 1422 hours (GL 1999; Kofod 2001). The highest hours of use appear to be for hospitals and major retailers, but overall the various European data sources point towards an average of about 1781 hours per year for the whole commercial building sector, as reported in Table 2. Looking outside the OECD values are in between European and other OECD levels. In Russia, lighting in commercial buildings is operated for an average of 1900 hours per annum (Aizenberg et al 2001), while in China values of about 2800 hours are reported (ACMR 2004).

Some contributory factors can be raised qualitatively that may explain these differences, but it is not possible to properly quantify them. A first observation is that European employment legislation is generally more restrictive than in other OECD regions and hours of work more tightly controlled; this will have some influence in driving down the average hours of lighting operation in some types of commercial buildings. A second factor pertains solely to offices, where open-plan designs are less common in the European office stock than other OECD regions. Lighting in open plan offices tends to be operated for longer than cellular offices, especially if the switching is not zoned. Furthermore, it is possible that a greater share of European open plan offices operate zoned switching than elsewhere, although it has not been possible to verify this.

Could the use of automatic lighting controls be an explanatory factor? There is only limited information on average adoption rates of automatic lighting controls in OECD different regions, but the few available sources do not suggest that Europe has higher adoption rates than elsewhere. For example, the Canadian year 2000 survey of commercial and institutional buildings, Table 3, found that about 17% of the total commercial building floor area had occupancy sensors and daylight dimming devices and that over 40/% had scheduling (time clocks).

Table 3. Use of lighting conservation control measures in Canadian buildings in 2000 (CIBEUS 2002)

Lighting conservation features	Share of total floor area with measure
Reflectors	38.2%
Energy efficient ballast	67.2%
Daylight controls	17.6%
Occupancy sensors	17.0%
Time clocks	40.6%
Manual dimmer switches	36.0%
Energy efficient lamps	59.5%
Other	12.4%

A Japanese survey found that 27% of office buildings had some type of lighting energy management controls (ECCJ 2003). An equivalent survey doesn't exist for Europe as a whole, but a survey of commercial lighting in six EU countries in 2000 (Kofod 2001) found that 97% of buildings used manual controls, 4% scheduling (timer switches) and only 3% some kind of automatic control (occupancy sensors, day-light dimming etc.). Even allowing for the possibility of the relative floor area coverage being higher once building area is taken into account these figures suggest it is not likely that European buildings have higher levels of automatic lighting control than elsewhere in the OECD and may well be lagging. It is possible; however, that people could be more inclined to manually deactivate lights (due to cultural factors), that a greater proportion of buildings have designated staff with the responsibility of turning off lighting after working hours and that daylight utilisation may be higher. This could arise in part because of a greater proportion of older buildings, which intrinsically made better use of daylight than many modern designs, but perhaps also because of prevailing architectural practice.

Whatever the cause, the net effect is that on average European commercial buildings do not activate their lights for as long as elsewhere in the OECD and this equates to very large relative energy savings. In aggregate the data suggests that European commercial buildings operate their lights 38% less frequently than the OECD average. When these factors are combined with the efficacy and power density characteristics European buildings use 32% less lighting electricity per unit area than the OECD average and 16% less than the country with the highest estimated average efficacy (Japan); this despite a mix of commercial sector lighting systems that are 23% less efficacious than in Japan.

The average estimated lighting energy intensity figures by commercial building type and region are shown in Figure 5, and reveal substantial differences from one OECD region to another. As mentioned that main cause of difference appears to be the length of lamp operation but variations in efficacy and illuminance levels also play an important role.

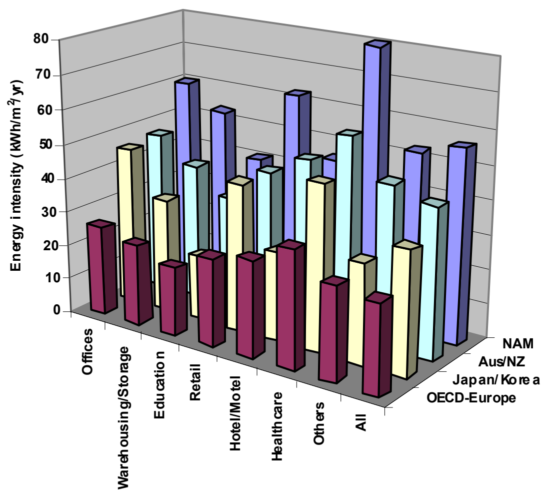

Figure 5 Estimated average commercial building lighting energy intensities in 2005 by OECD region

USA and Canada

According to the US Lighting Market Characterisation Study (Navigant 2002), which is based on a sophisticated marriage of the findings of almost 25000 utility lighting audits and the national commercial building energy consumption survey of 5430 buildings, commercial buildings accounted for 391 TWh of lighting electricity consumption in the year 2001. Across the whole sector some 1.97 billion lamps were installed of which 22% were incandescent/halogen, 77% fluorescent and 2% HID.

The average lamp operated 9.9 hours per day and drew power of 56W. Incandescent and halogen lighting consumed 125 TWh (32%), fluorescent lamps 220 TWh (56%) and HID lamps 46 TWh (12%). The sector comprised 4.7 million buildings with a total floor area of 6.3 billion square metres and an average lighting electricity intensity of 60.9 kWh/m^2. This produced 3.4 M-lm-hrs of light per square metre at an efficacy of 49.5 lm/W. From this assessment the commercial sector accounts for 51% of total lighting energy use in the USA. The Navigant assessment follows on from earlier surveys that had estimated significantly lower levels of commercial sector lighting consumption in the USA, notably 240 TWh (Vorsatz *et al* 1997) and 340 TWh (EIA); however, as it is more comprehensive than its predecessors and is based on a far richer set of survey data it takes precedent.

Canadian commercial buildings consumed 43.9TWh of electricity for lighting in 2003, which is 33% of all Canadian commercial sector electricity consumption, at an average intensity of 80.2 kWh/m^2 (NRC 2006). In 1990 the commercial sector used 37.2 TWh for lighting thus demand grew at an average of 1.3% pa in the intervening years. The share of total Canadian commercial building energy use taken by lighting fluctuated between 14.6 % and 15.6 % since 1990. Of total lighting consumption, 36.6 % was in offices, 25.4 % in retail organisations, 11.4 % in health care facilities and 9.6 % in warehouses. Street lighting, discussed in section 4.2.5, consumed 7.7 %.

Europe
There have been a diverse set of estimates for commercial lighting energy use in Europe and this continues to present a problem in properly characterising the sector. The European Climate Change Programme made an estimate of 135.4 TWh for the former EU-15 in 1995, which amounts to 28.5% of the total electricity use for the sector; however, this was based more on a synthesis of expert opinion than a formal survey (Waide 2001). Blok et al (1996) estimated that lighting accounts for ~38% of European commercial sector electricity use, which would represent an EU-15 commercial lighting total of 185 TWh in 1995. A previous study (BRE 1994) estimated commercial sector lighting consumption in the previous EC-12 countries to be 110 TWh/year, circa 1992, which translates into a lighting energy intensity of approximately 27.9 kWh/m^2. The BRE study has been a cornerstone of many EU estimates in this sector and informed the Directive on ballast energy performance, but was only based on scaled-up estimates from three EU countries (UK, Germany and the Netherlands) that have since been called into question by more recent detailed work. For example, the UK Market Transformation Programme recently made detailed national estimates based on building survey data and a bottom-up stock model and concluded that UK commercial sector lighting amounted to 41.9 TWh in 1994[6]. This translates to a lighting energy intensity of 52.3 kWh/m^2; some 77% higher than estimated in the BRE study and 48% higher than the ECCP assessment for 1995. A similar survey in the Netherlands found an average commercial sector lighting intensity of 51.1 kW/m^2 for the same period (ECN 1999), which is the same value as used in the ECCP assessment but 18% higher than in the BRE study. Data from Portugal gives an intensity of 14.8 Wh/m^2 (GASA-FCT 2000), which is 15% higher than estimated for the same country in the ECCP analysis and 57% higher than in the BRE study. Similarly, more anecdotal but high quality data from end-use metering campaigns targeted on specific commercial building types, conference papers etc., suggest that the BRE lighting energy intensity estimates are too low and the ECCP estimates are also somewhat low.

The situation is no less confusing when looking at lighting in individual commercial building types. The European Greenlights study estimated EU-15 lighting energy consumption of 28.8 TWh for office buildings and 15.0 TWh for educational buildings (GL 1999). When converted into lighting energy intensities this amounts to 46.3kWh/m^2 and 29.7 kWh/m^2 respectively. However, these figures are higher than those found in a survey of lighting in commercial sector buildings for six EU countries that reports average values of 18.0 kWh/m^2 and 15.1 kWh/m^2 (Kofod 2001). French data (EDF 1996) suggests 34 kWh/m^2, or more recently 26.7 kWh/m^2 (Enertech 2005) for offices and 44kWh/m^2 for retail. The BRE (1994) found intensity values for retail of from: 48 kWh/m^2 for Germany to 87 kWh/m^2 for the Netherlands. Kofod (2001) found national average ranges of from 10.3 to 83 kWh/m^2 for shop floor areas and between 39kWh/m^2 and 450 kWh/m^2 for shop window display areas. This gave average lighting intensities of 50.2 kWh/m^2 for shop floors and 201 kWh/m^2 for display areas.

[6] www.mtprog.co.uk

These myriad data sources present quite a confusing picture and one that is in need of further verification and structuring. Given the large uncertainties in current EU estimates it seems more reliable to use a consistent bottom-up accounting framework to derive estimates, as has been done for the work presented here.

The current IEA analysis estimates that commercial sector lighting in the European member countries of the OECD consumed 185 TWh in 2005, which is higher than the earlier values reported by the European Commission's Climate Change Programme and the preceding BRE study and implies a sector average lighting intensity of 25.7 kWh/m^2.

Japan
The Japanese Luminaire Association estimated that commercial buildings would consume 52.2 TWh of electricity in 2005, which is 40% of total lighting consumption in Japan. This equates to a lighting energy intensity of 29.9 kWh/m^2 (JLA 2005). It is not known how the JLA estimates are derived or whether there is solid metered data to support the analysis. The difficulty experienced in the USA and Europe in obtaining reliable estimates of commercial lighting energy use suggests that it is not a simple exercise and that considerable effort is needed to gain accurate values. The current sources imply lighting accounts for 18% of all commercial building electricity use in Japan, which is a much lower share than reported in other OECD regions.

Australia
Commercial lighting in Australia was estimated to have consumed 11.4 TWh in 1998 (Ellis 2001). As in other regions it is dominated by LFL tubes, most of which are of the T8 halo-phosphor type in line with Europe and China.

Commercial lighting characteristics in non-OECD countries
An estimated 422 TWh of electricity was used for commercial lighting in non-OECD countries in 2005, which is 37% of the world total in this sector and 41% of non-OECD commercial building electricity consumption. This provides illumination for 17.5 billion m^2 of floor area at an estimated average intensity of about 24.1 kWh/m^2 and average efficacy of 52.6 lm/W. Both the floor area and the average intensity are growing much faster than in the OECD in line with the faster average rate of growth rate being experienced in non-OECD countries; however, this growth is very uneven and a wide diversity of values are found.

The cost of the light provided averages about US$3.3 per m^2 per annum or some US$57 billion for the non-OECD as a whole. As with the OECD, electricity costs are about 60% of the total and the remaining 40% is the cost of the lighting equipment (lamps, luminaries, ballasts & controls), installation and maintenance labour. The average cost of delivered light is US$2.6 per M-lm-hr but local costs can vary significantly from this depending on tariffs and lighting system efficiency. In almost all cases the highest efficiency lighting systems have the lowest life cycle costs, thus raising commercial sector lighting efficiency almost always makes sense in economic terms.

With some exceptions the data on commercial lighting electricity consumption is not as good in non-OECD countries as OECD countries, but enough is known to observe some important similarities and differences, as well as to enable regional estimates to be formulated. As in the OECD, fluorescent lamps predominate but there are many differences from one region to another regarding the preferred linear fluorescent technology. In Thailand, for example, DSM programmes in the early 1990s effectively phased out T12 production in the country in favour of T8s. These now dominate the Thai market, although the vast majority are the less efficient halo-phosphor variety. T12s appear to be have almost disappeared from the Chinese market too if the data in the ACMR (2004) survey is correct.
By contrast in many other regions T12s are still very commonplace and overall they occupy a large part of the non-OECD LFL market. In Russia, for example, the average LFL efficacy in the installed commercial stock is estimated to have been 65 lm/W in the year 2000 (Aizenberg et al 2001), suggesting that poor quality T12s and low efficiency electromagnetic ballasts were commonplace. In South Africa commercial lighting has been switching over toward T8s from T12s, but with several

years lag compared to Europe (Henderson 1997). In the Indian sub-continent it appears that T12s are still the dominant LFL lamp type. Given, this and the poorer than average efficiency of ballasts sold in non-OECD countries it may come as a surprise to discover that the average efficacy of lighting in commercial sector buildings could be higher than in the non-OECD regions compared to the OECD as a whole; however, this is explicable by seemingly lower share of incandescent lamps compared with OECD buildings.

The estimated average commercial sector lighting power density in China for the year 2000 is 9.7 W/m^2, which is appreciably lower than in the OECD, mostly because of lower installed light levels. Across the combined commercial and industrial sectors some 1.37 billion lamps were installed in 2003 of which 25% were incandescent/halogen, 67% fluorescent and 8% HID. The average lamp operated 8.1 hours per day and drew an estimated power of 58W. Incandescent and halogen lighting consumed 37 TWh (25%), fluorescent lamps 62 TWh (41%) and HID lamps 50 TWh (33%). These values give rise to an estimated commercial sector lighting energy intensity of 23.5 kWh/m^2, which is 60% of the OECD average despite China having slightly greater than OECD-average annual lighting operating hours.

In Russia, however, commercial sector usage of incandescent lighting appears to be remarkably low, as this is reported to provide just 3.3% of the source lumens in 2000 (Aizenberg et al 2001). Overall in non-OECD countries it is estimated that incandescent and halogen lamps only provide 4.8% of commercial sector lighting. This is lower than in the OECD as a whole and explains why average commercial lighting sector efficacy is thought to be slightly higher.

4. Projected consumption, savings and potentials

The IEA analysis is more than just an attempt to characterise current lighting energy consumption: it also includes an assessment of the impact of past lighting energy efficiency policies implemented since 1990 and includes projections of future lighting energy use to 2030. These projections are based in part on the characterisation outlined above but also rely on historic time series of lighting data and information about programme types and impacts.

Future consumption with current policies

With current socioeconomic patterns and policies the global demand for artificial light in commercial buildings is forecast to attain 96 peta-lumen hours by 2030, which represents an average annual growth rate over the next two and a half decades of 1.9%. However, this projected growth is the aggregate result of many, sometimes divergent, trends. Average consumption of source lumens per unit floor area of tertiary buildings in IEA countries is likely to fall, for example, as measures continue to take effect that improve the efficiency of lumen delivery and reduce lumen wastage. As demand for artificial light grows so does the energy consumption required to supply it; yet, thanks to numerous efficiency improvements at a far slower rate. Over the last decade it is estimated that global electricity consumption for commercial building lighting applications grew at 0.5% per annum, which is just over a quarter of the rate of growth in demand for light. This decoupling of energy from service growth is because of the use of more efficient lighting technologies driven in large part by proactive lighting energy efficiency policies in OECD countries and increasingly non-OECD countries too. Nonetheless, over the next 25 years global electricity consumption for commercial building lighting with current socioeconomic trends and policies is projected to rise to over 1470 TWh: an increase of 30% at an average rate of 1.0% per annum, Figure 6 “Current Policies” scenario. The rate at which growth actually occurs will depend on a range of factors including those which influence demand for artificial light and on the efficiency of the lighting technologies which supply it.

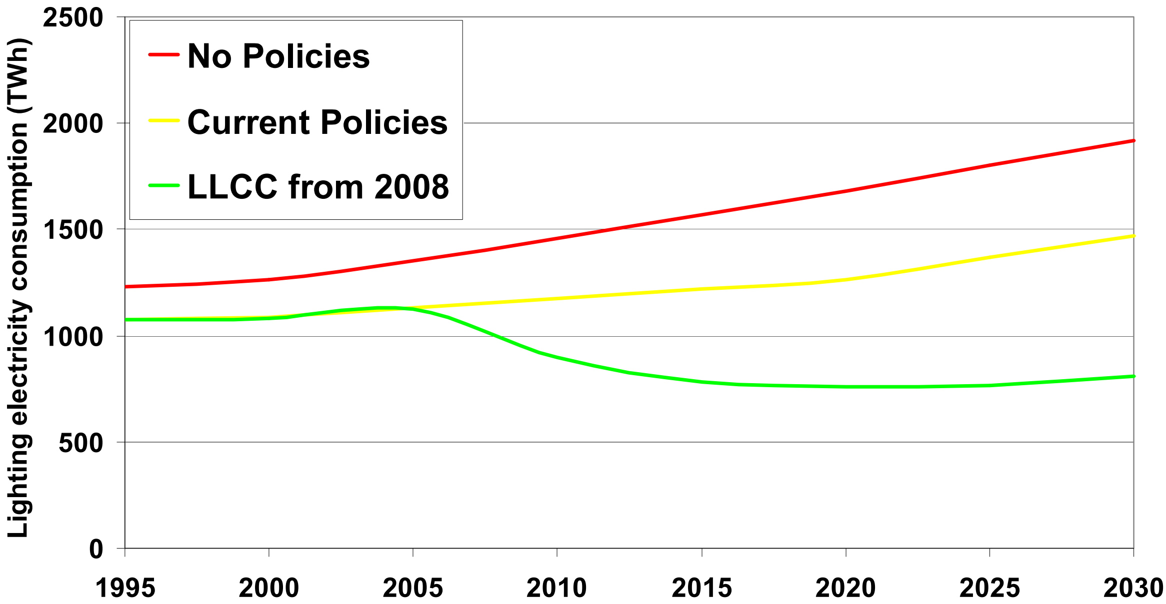

Figure 6. Global commercial sector lighting electricity consumption under No Policy, Current Policy and Least-Life-Cycle Cost 2008 scenarios, 1990 to 2030

Current policies are saving a lot of energy
At various times all IEA member countries have implemented policies to encourage more efficient lighting and all currently have some policies in place. These policies can be divided into those that apply to the lighting-system components and those that apply to the system as a whole. The former include regulatory measures, such as energy labelling and lamp and ballast minimum efficiency requirements, but can also include information, incentives, such as subsidies for the purchase of efficient equipment and agreements with industry to discontinue production and marketing of outdated technologies.

The latter most commonly include guidelines or mandatory requirements regarding the efficiency of new and/or retrofit lighting installations. Since 1989 a progressively larger number of US and Canadian states have introduced mandatory building codes that specify minimum energy performance requirements for new lighting systems. This mostly involves imposition of maximum lighting system power density limits (power use per unit floor area) but increasingly involves specification of minimum requirements for lighting controls too. Six EU countries have similar requirements and the remainder are in the process of developing related policies under the auspices of the 2001 Energy Performance in Buildings Directive. The impact of these measures is uncertain, largely because the level of compliance is not fully known, but is thought to be highly significant. In the USA and Canada, for example, we estimate that a mixture of Federal component standards and state building regulations, which have come into force from 1990 onwards and numerous utility energy conservation programmes are currently saving 144 TWh of lighting energy demand in commercial buildings each year compared with what would have been the case had they not been implemented. This is 32% of current commercial sector lighting energy consumption in the region and amounts to annual savings of over 18 kWh/m^2 of commercial building floor area. Similar programmes in other IEA countries launched over the same time frame are estimated to be lowering commercial building lighting energy consumption by between 25 and 41%. These assessments may only give part of the picture; however, as measures which directly influence component efficiency or average installed wattages per unit area are easier to evaluate than those which encourage the deployment of daylight or more effective lighting control. There is a degree of evidence, for example, that lighting energy consumption in some European countries has been limited by relatively successful efforts to curb the lamp operating hours and utilise daylight.

In less developed countries there have also been many positive experiences with lighting energy efficiency policy although much of this has been orientated at residential and public lighting rather than the commercial building sector. Thailand, Brazil, Mexico and China are countries where policy measures have been implanted in recent times that will have some impact on commercial lighting energy efficiency. In general though there has been less activity in the commercial sector and most developing countries do not have building energy codes. Of the few which do even fewer have provisions for lighting. China's newly developed building lighting code is an important exception. Such is the rate of new construction that it has been estimated that if this code is fully-complied with it will avoid the increment of an additional 10.7 TWh of electricity demand each year in commercial buildings alone. This is equivalent to offsetting the need for a new Three-Gorges dam project every 8 years! In fact these figures are conservative because they take no account of the electricity saved from lower internal heat gains and hence lower air conditioning loads. Most electricity networks in China are summer peaking and each lighting watt saved avoids an additional 1/3 to ½ watt of air conditioning power demand.

It is estimated that existing lighting energy efficiency policies for commercial buildings including building codes, minimum energy performance standards for lamps and control gear and market-transformation programmes are saving 220 TWh per annum globally and will go on to save 445 TWh in 2030 even if they are not strengthened in the future, Figure 6: compare the "No Policies" and "Current Policies" scenarios. This amounts to 30% of global commercial building lighting consumption in 2030 and will not only save end-users US$66 billion in total lighting costs but will avoid 260 Mt of CO_2 emissions at a negative net cost of US$–254 per tonne. However, there are large uncertainties in this assessment, not least because insufficient information is available regarding the level of compliance with existing policy requirements. The sparse data that are available suggest that current compliance with building code provisions for lighting is poor and, consequently, a large amount of cost-effective energy savings is being squandered.

There is a very large cost-effective potential to reduce commercial lighting energy demand
Even in those regions with the most developed policy frameworks the potential for further cost-effective savings from strengthening lighting efficiency policies and their implementation remains great. The current global average cost of electric light in the commercial sector is about US$2.5 per mega-lumen hour, of which 58% is the energy cost and the rest is the cost of equipment (lamps, luminaries and control gear) and labour needed to install and maintain the lighting systems. The use of lighting systems which minimise lifecycle costs (i.e. so called "least-lifecycle cost" lighting systems) lowers the average cost of light by over 30%.

We estimate that the systematic deployment of least-life cycle cost lighting solutions from 2008 onwards would substantially reduce the energy consumption attributable to lighting. The resulting consumption is 40% lower in 2020 than would be expected from continuing with the current set of policies, which avoids the consumption of 505 TWh of electricity and 300 Mt of CO_2 emissions. By 2030 annual savings would rise to 661 TWh and 404 Mt of CO_2 respectively. The full adoption of least-life cycle cost lighting will save end-users US$37 billion in total annual lighting costs (equipment, energy and labour) by 2020 and US$47 billion by 2030. The global net present value of these cost savings assuming a 5% real discount rate and discontinuation of benefits after 2030 is US$188 billion. As, by definition, implementing least-life cycle cost lighting saves end-users money the cost of avoiding carbon dioxide emissions through these measures is estimated to be negative at: -US$119 per tonne of CO_2 in 2030.

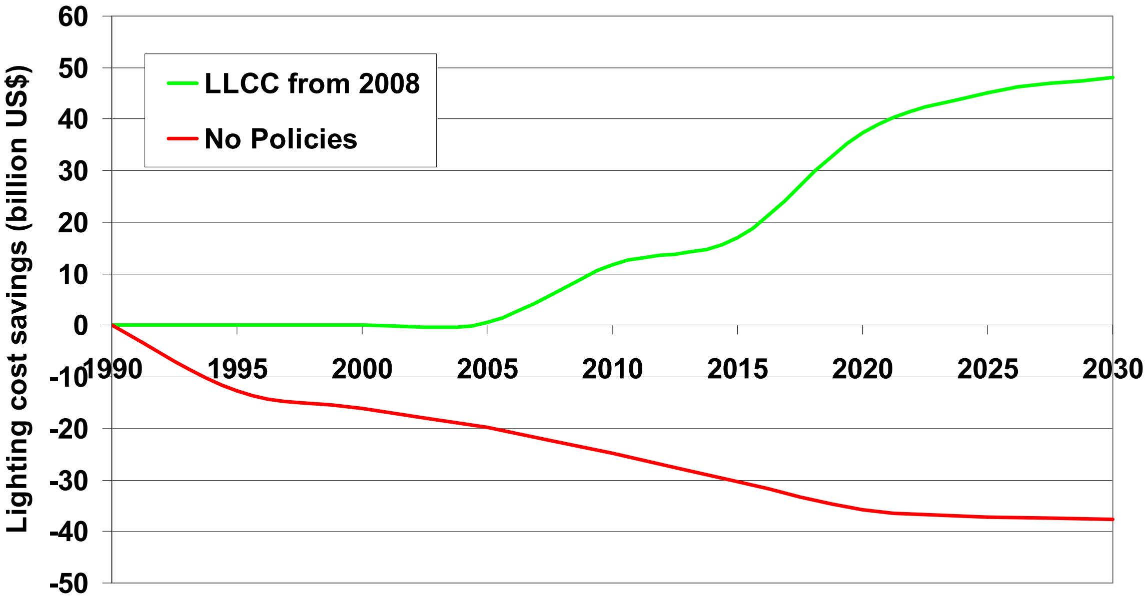

Figure 7. Savings in overall lighting costs compared with Current Policies (million $US)

The high potential for energy savings in lighting reflects the fact that there are already many cost-effective energy-efficient lighting technologies available on the market but which are currently underutilised. The estimated savings potentials presented above are based on today's artificial lighting technology and today's average prices; however, new lighting technologies are under development which promise higher levels of efficiency and that could further increase the cost effective savings potentials to 2030. Furthermore, the above estimates take no account of the cost-effective potential to increase daylight utilisation beyond the selective use of automatic dimming systems in spaces already having access to daylight. Lastly, the calculations take no account of the reduction of parasitic lighting-induced energy loads such as air conditioning, nor the typical high peak-power coincidence factor of many lighting loads that increases the value of their savings compared to average electricity loads. Were all these factors to be fully taken into consideration the cost effective savings potential could be substantially greater.

5. Conclusions

There has been a pronounced improvement in commercial lighting energy efficiency over the last 15 years and much of this is attributable to proactive energy efficiency policy measures. The energy saved has been remarkably cost effective and yet there remains much more to be done to optimise the lighting energy service from a cost, quality and environmental impact perspective. The analysis of the policies that have bought about these savings and the resulting benefits are given in *Light's Labour's Lost*[7]. Despite this analysis in some IEA Member countries shows that energy-efficient lighting is deployed in well under half of commercial buildings, and the figure is usually lower elsewhere. Much remains to be done both in the private sector and public, through stronger policy settings, if the enormous cost-effective savings potentials identified in this analysis are to be realised. Key issues within the regulatory environment include the stringency of overall power density requirements (the installed lighting system's power requirements per unit area, expressed in units of watts/m^2 of W/ft^2 in the USA) and the nature of general lighting requirements (which may require high and/or uniform levels of illumination, even though this may lead to over-lighting of infrequently-used or 'uncritical' areas of buildings and may pose a regulatory barrier to daylighting). Few building codes demand automation systems, or optimal use of available daylight, and not all codes require zonal or individual luminaire switching. Moreover, many countries, including IEA members, still have no regulatory requirements for lighting in their building codes nor have any minimum energy performance

[7] See publications at www.iea.org

standards to prohibit the sale of less efficient lamps. Only California and the UK have any measures which address luminaire performance despite the high potential for savings through improved performance. Ballast energy performance requirements are also neglected or weak in many IEA and non-OECD countries alike.

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Abstract
This book contains the Proceedings of the 4th International Conference on Improving Energy Efficiency in Commercial Buildings - IEECB'06 which was held in Frankfurt, Germany, 26 - 27 April 2006. The IEECB'06 conference has been very successful in attracting a large international audience, representing a wide variety of stakeholders involved in policy implementation and development, research and programme implementation, investments and property management of energy efficient commercial buildings. IEECB'06 has provided an unique forum to discuss and debate the latest developments in energy and environmental impact of commercial buildings and the installed equipment and lighting. The presentations were made by the leading experts coming from virtually every corner of the world. The presentations covered policies and programmes adopted and planned in several geographical areas and countries, as well as technical and commercial advances in the dissemination and penetration of energy efficient commercial buildings.

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