Evaluation of building envelope retrofit techniques for reducing energy needs for space cooling

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Keywords

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Abstract

One of the fastest growing sources of new energy demand is space cooling. According to EU-studies a four-fold growth in air-conditioned space is likely to take place between 1990 and 2020. The energy savings achievable in the end-use space cooling depend on a number of variables related to the building envelope, the plants and to some extent the behaviour of occupants. They are hence complex to evaluate and consequently often underrepresented in energy efficiency programmes and National Plans.

This paper is based on some preliminary results of the IEE project KeepCool 2. It discusses in particular:

- a methodology for bottom-up assessment of the energy savings related to "sustainable summer comfort" solutions; reference base case building typologies are analyzed in 5 European climates, and dynamic simulations are used to calculate the reductions in the energy need for cooling which can be achieved by specific retrofit actions (e.g. additions of effective solar protections, increased thermal insulation, night ventilation, increase of active mass by PCM, low solar absorbance surfaces,…); situations where mechanical cooling can be avoided are evaluated using the Adaptive Comfort model, according to the norm EN 15251.
- case studies of buildings with good summer comfort and low energy consumption performances, according to the ten steps of the KC2 procedure.
- the analysis of case studies of "comfort policies" adopted by public and private bodies to ensure summer comfort with low energy consumption (commitments to give priority to heat load reductions instead of introducing mechanical cooling, relaxed dress codes, low thermal insulation chairs, local air velocity increase).

Introduction

One of the fastest growing sources of new energy demand is space cooling. The studies EECCAC and EERAC predict a four-fold growth in air-conditioned space between 1990 and 2020 (Adnot, J. et Al, 2003). The IEA Future Building Forum even named cooling as one of the fastest growing sources of new energy demand (International Energy Agency, 2004).

In its preamble, the European Energy Performance of Buildings Directive (EPBD) states that "Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings" (European Communities, 2003, p. L1/66).

But such passive cooling technologies, which are already available and cost effective (such as use of well designed sun shades, efficient lighting and office equipment, passive cooling via thermal exchange with the ground, night ventilation etc.) are not widely used on the market today: the most common choice for a building owner when addressing summer comfort issues is still mechanical cooling, often without previously investigating other available measures regarding the optimization of envelope features (e.g. solar protections, glazing solar factor, thermal insulation of opaque surfaces, thermal mass). Only a limited number of retrofit actions taking into account passive cooling options have been documented in detail (see e.g. Burton 2001)

This paper is based on some preliminary results of project KeepCool2 (KC2 in the following) to contribute to a broad market transformation from "a cooling approach" to "a sustainable summer comfort approach" which makes effective use of

- the most advanced knowledge and technologies for good design of building envelope (or redesign through retrofit actions)
- passive cooling techniques and
- comfort responses and adaption mechanisms of occupants (according to the new European Standard EN 15251/2007, (CEN 2007a), (Nicol and Pagliano 2007))

In this paper "sustainable summer comfort" is defined as "achieving good summer comfort conditions with no or limited use of non renewable energy[1] and through the use of environmentally non-harmful materials" (Varga and Pagliano 2006), according to the definition set up in the KeepCool project (see also http://www.keep-cool.net/keepcool.html)

Sustainable summer comfort solutions: a methodology for the assessment of potential savings in existing buildings

One of the KC2 objectives consists in developing an approach for a bottom-up assessment of the energy savings related to sustainable summer comfort solutions. The main results of this work will be "benchmarks" of gross annual energy savings related to typical existing buildings and to single or packaged technical measures of sustainable summer comfort. These results could be useful both for actors of the field (engineers, building designers…) and national public authorities. Indeed, this quantified information will allow comparisons between summer comfort solutions, determination of the most efficient solutions as well as a possible evaluation methodology for energy savings as input to National Energy Efficiency Action Plans.

OVERVIEW OF THE METHODOLOGY

Scope

It has been decided to focus on existing buildings and on technical Energy Efficiency Improvement (EEI) actions which are defined as technical actions taken at an end-user's site (or building, equipment…), but not necessarily by the end-user himself, that improve the energy efficiency of the energy end-using facilities or equipment, and thereby save energy. An end-use action can be taken individually and evaluated separately (e.g. installation of solar shading). Behavioural or organizational actions (e.g. increase of temperature set-points) will not be treated in this analysis.

The main objective of WP 4 is therefore to provide benchmark of energy savings implied by the implementation of EEI actions (relative to summer comfort) in European existing buildings.

Main steps

The assessment of energy savings related to summer comfort solutions is based on three main steps that are presented with more details in the following sections:

- Definition and specification of reference cases. Since the work consists in an ex-ante evaluation we have chosen to base our approach on building simulations. Then, it is necessary to define reference cases (i.e. buildings considered as representative of the European building stock) to which summer comfort solutions will be applied and assessed. Furthermore, it is also necessary to define several climatic areas for Europe in order to reduce the number of building simulations.
- Selection of technical solutions suitable for a quantitative assessment. EEI action and packages of EEI actions that are worth to be studied (enough knowledge is available for their assessment, available on the market…) are determined along with buildings suitable for these actions.
- Evaluation of energy savings. This builds up on the two previous steps by evaluating the energy savings related to the implementation of a given (package of) sustainable summer comfort solutions in the predefined typical reference base cases. This third step requires the development of a methodology and set of hypothesis presented in this paper.

Expected outcomes

The expected outcomes are a benchmark of default values in terms of reductions of energy need and savings of primary energy. It is also planned to make a simplified tool that will allow more flexibility to the user: for some inputs like appliances efficiencies or the electricity/primary energy conversion factor, she/he can either choose the default values or take her/his own values.

BASE CASE DETERMINATION

Definition of climatic areas

Assuming that solar radiation and cooling degree days are the key parameters regarding summer severity, the global solar radiation has been summed and cooling degree days have been calculated over a year for 30 European cities: at least one city per EU-25 country (except Luxembourg for which Nancy has been kept and Gdansk for Lithuania) and several cities for France, Italy and Spain. Furthermore, the severity of winter is also an important parameter in our study: on the one hand this has an important impact on building characteristics and on the other hand, the improvement actions we are going to study also impact heating energy needs..Buildings will be simulated in a number of cities representatives of the EU climatic areas (e.g. Stocholm, Paris, Milan; Lisbon, Palermo,…)

1. non-renewable energy is defined as energy taken from a source which is depleted by extraction (e.g. fossil fuels) in the European Standard prEN 15603:2007: E., (CEN 2007b)

Table 1. Geometrical description of office base cases

	Number of floors	Space disposition	Glazed areas [% of the vertical surface]
Office building n°1	12	Open space	45
Office building n°2	2	Cellular	30
Office building n°3	4	Open space	15
Office building n°4	5	Cellular	40

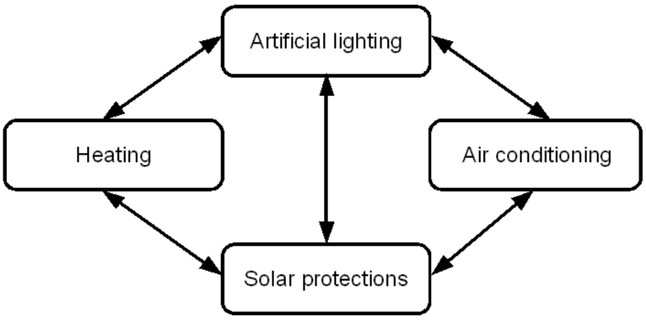

Figure 1. Example of interactions between actions

Table 2. List of EEI actions being analysed

EEI actions to be studied	Offices	Retails	Flats
Install an external movable screen blind	X		X
Install an external movable screen blind with radiation control	X		X
Install an external movable Venetian blind	X		X
Install an external movable Venetian blind with radiation control	X		X
Install an external window awning		X	
Install efficient windows	X	X	X
Treat wall and roofs with special paintings	X		X
Insulate the roof	X		X
Install Phase Change Material (PCM) plasterboard	X	X	X
Use energy efficient office equipment	X		
Install energy efficient lightings and ballasts	X	X	
Install automatic night-time operable openings	X		
Install automatic day and night time operable openings	X		
Install extraction system for night-time ventilation	X		
Install extraction system for day and night-time ventilation	X		
Use an existing ventilation system at full speed for night-time ventilation	X	X	
Use an existing ventilation system at full speed for day and night-time ventilation	X		X

Definition of building reference cases

Regarding their respective importance in terms of cooling surface, three sectors have been chosen for the study (residence, commercial, office). A flat and a small retail are defined as reference case for the residential and commercial sectors. Regarding the office sector, since it represents most of the air conditioned surface, it is represented by four reference cases whose brief descriptions are given in the Table 1.

Building characteristics depend on the climatic area and are supposed to be representative of existing building. Project members coming from the five representative cities (Swedish Energy Agency, Ecole des Mines de Paris, eERG, INETI for Portugal) filled in an information request about the existing building stock in their country. A detailed description of the base cases can be found on the KeepCool 2 website.

SELECTION OF SOLUTIONS TO BE SIMULATED

Based on the KeepCool I project ([Varga, 2007]), a rather complete list of possible improvements related to summer comfort has been compiled, with a description of the physical principles, the technical implementation and the conditions of applicability. Although it is theoretically possible to apply most of the technologies to any type of building, for practical and economic reasons some of them are mainly suited for new buildings and not existing ones. Then, the data required for the simulations have been gathered: technical characteristics, performance level…The final list of EEI actions that are being simulated in order to evaluate savings is given in Table 2 (technical specifications can be found on the KC2 website).

A main issue regarding savings evaluation is interaction between measures. If two actions A and B are both implemented, the combined action AB will not save as much energy as the sum of the two individual actions' savings. Figure 1 gives examples of interactions that must be faced when dealing with summer comfort (an additional interaction could be added between air conditioning and heating in case of plants based on reversible heat pumps). As a result, EEI actions listed in Table 2 must be studied not only individually but within packages.

PRESENTATION OF THE METHODOLOGY FOR THE EVALUATION OF ENERGY SAVINGS

What does "energy saving" mean in our context?

Contrary to other sectors (lighting, heating, refrigerators…), air conditioning penetration in buildings is not close to saturation since a relevant part of the European building stock is not cooled or air conditioned. This particularity must be analyzed: if it is possible to estimate and even measure energy savings in AC buildings as the difference in consumption after and before the action, how to deal with the others? EEI actions relative to summer comfort in non AC buildings do not reduce the amount of energy currently consumed, but they contribute to reduce or avoid the consumption connected to the possible installation of new active AC systems and in this way, save energy compared to the expected consumption trend in the next years.

The situation is therefore the following.

EEI actions in AC buildings will reduce the energy need for cooling. In some cases, the energy need for cooling can be reduced sufficiently so that there is no need for active cooling or the energy need can be met with a sustainable passive cooling solution.

Naturally ventilated buildings can be comfortable or non comfortable in summer (comfortable buildings can also become uncomfortable during extreme events like heat waves and owners can look for a cooling solution). Theoretically, we are only interested in uncomfortable ones and face two possible situations:

a. Some EEI actions will improve the comfort (reduce the number of overheating hours).

b. Some EEI actions (rather packages of actions) will make the building comfortable and hence eliminate the need for air conditioning.

In situation "a", we suggest using the same saving value than for AC buildings whereas in situation, "b" the total consumption of the reference building (AC) can be taken as obtained saving.

General approach

The proposed methodology for calculations is represented in Figure 2 and explained hereafter. We propose to study buildings (reference ones or improved ones) in two ways: air conditioned and naturally ventilated (with the possibility to open the windows).

Regarding AC buildings, we define comfort conditions to be reached (based on existing standards, mainly EN 15251) in the base case (BC) and in the base case + Energy Efficiency Intervention (BC+EEI). Then, we suggest calculating the "energy need" to reach this comfort objective for the base case and for the case when a given EEI action has been implemented. From energy needs it becomes possible to calculate the final and primary energy consumptions for the base case and for the case when a certain EEI action has been taken (assuming default efficiency values for distribution systems and generation plants).

Regarding naturally ventilated buildings, the simulations enable to derive comfort indices. Then, a comfort criterion (indoor conditions that are considered as comfortable in free ventilated buildings) must be taken into account to conclude if the EEI action (or package) implies a reduction of the cooling load or enables to avoid the use of air conditioning

Main equations

Calculation of unitary gross annual savings in cooling needs

Annual savings in terms of cooling needs (CN) are determined using the following equation:

- If even applying the Energy Efficiency Intervention the comfort criterion is not fulfilled and some cooling need remains :

$$\Delta\_CN = CN_{ref} - CN_{EEI}$$

- If applying the Energy Efficiency Intervention the comfort criterion is fulfilled and hence $CN_{EEI} = 0$:

$$\Delta\_CN = CN_{ref}$$

Where:

Δ_CN is the annual saving in terms of cooling needs [kWh/m²/y]
CN_{ref} is the annual cooling needs of the reference case obtained from simulations [kWh/m²/y]
CN_{EEI} is the annual cooling needs of the reference case in which the EEI action has been applied obtained from simulations [kWh/m²/y]

Calculation of unitary gross annual savings in heating needs

Annual savings in terms of heating needs are determined using the following equation:

$$\Delta\_HN = HN_{ref} - HN_{EEI}$$

Where:

Δ_HN is the annual saving in terms of heating needs [kWh/m²/y]
HN_{ref} is the annual heating needs of the reference case obtained from simulations [kWh/m²/y]
HN_{EEI} is the annual heating needs of the reference case in which the EEI action has been applied obtained from simulations [kWh/m²/y]

Calculation of unitary gross annual savings in terms of final energy

A distinction should be made between electricity savings and fuel savings.

Annual electricity saving is the sum of electricity savings due to heating and due to cooling:

$$\Delta\_E_C = \frac{\Delta\_CN}{SEER}$$

$$\Delta\_E_H = W_{EUE} * \frac{\Delta\_HN}{\eta_{EUE}}$$

As previously explained, interactions between energy end-uses must sometimes be taken into account (for example the increase of artificial lighting due to solar protection of efficient windows) and added or subtracted to electricity savings due to heating and cooling.

Annual fuel savings are assumed to be the result of heating needs reduction:

$$\Delta\_F = W_{FUE} * \frac{\Delta\_HN}{\eta_{FUE}}$$

where:

Δ_E_C is the annual savings in terms of electricity stemming from cooling demand reduction [kWh/m²/y]

Δ_E_H is the annual savings in terms of electricity stemming from heating demand reduction [kWh/m²/y]

Δ_CN is the annual saving in terms of cooling needs [kWh/m²/y]

$SEER$ is the Seasonal Energy Efficiency Ratio in cooling mode representative of the AC existing stock

Δ_HN is the annual saving in terms of heating needs [kWh/m²/y]

Δ_F is the annual savings in terms of fuel [kWh/m²/y]

η_{FUE} is the Seasonal efficiency in heating mode representative of the stock of fuel using equipments

η_{EUE} is the Seasonal efficiency in heating mode representative of the stock of electricity using equipments (heat pump, resistive…)

W_{EUE} and W_{FUE} are the repartition factors between electricity using equipments and fuel using equipments. ($W_R + W_B = 1$).

Comfort assessment

When dealing with thermal comfort, a distinction must be made between two terms:

- A comfort index is an information on the indoor comfort (for example: hourly temperature, hourly PMV) based on measured physical variables and some hypothesis about their interpretation
- A comfort criterion is a factor that allows making a judgment on indoor thermal comfort at a given time (often on an hourly basis) or over a given period. For example the fact to say that "when the temperature is higher than 26°C the situation is uncomfortable" is a short term criterion whereas "when the temperature is higher than 26°C more than 10% of the occupation time, the building is uncomfortable" is a long term criterion.

In the developed methodology, in order to conclude if an EEI action could enable to avoid the installation of conventional air conditioning systems we must study the indoor climatic conditions and provide comfort indices. They are based on the new European Standard EN 15251 (CEN 2007a) defining thermal comfort conditions and consist in the percentage outside range and degree hours criterion based on adaptive comfort range (Category I and II), fixed operative temperatures (default values of the standard), PMV (category I and II) with flexibility on clothing…

In particular the "percentage outside the range" method requires to calculate the number or % of occupied hours (those during which the building is occupied) when the PMV or the operative temperature is outside a specified range.

In the "degree hours criteria": the time during which the actual operative temperature exceeds the specified range during the occupied hours is weighted by a factor which is a function of by how many degrees the range has been exceeded.

The weighing factor, w_f, equals 0 for $\Theta_{o,\ limit,\ lower} < \Theta_o < \Theta_{o,\ limit,\ upper}$ where $\Theta_{o,\ limit}$ is the lower or upper limit of the comfort range specified (e.g. 23,0°C < Θ_o < 26,0°C corresponding to –0,5 < PMV < 0,5 as specified in Annexe A for single offices, category II, summer). The weighing factor, w_f, is calculated as $w_f = \Theta_o - \Theta_{o,limit,}$ when $\Theta_o < \Theta_{o,limit,lower}$ or $\Theta_{o,limit,upper} < \Theta_o$

For a characteristic period during a year, the product of the weighting factor and time is summed. The summation of the product has the unit of hours.

Warm period: $\Sigma w_f \cdot$ time for $\Theta_o > \Theta_{o,limit,upper}$

Cold period: $\Sigma w_f \cdot$ time for $\Theta_o < \Theta_{o,limit,lower}$

Other indexes will also be evaluated (Pagliano and Zangheri 2005). Then it is up to the user to choose the comfort criterion and the conditions from which the building is assumed to not require AC. The default criterion used to derive default values is that a building is assumed to be comfortable if the percentage of time outside zone is lower than 5% over the summer. The default zone is the adaptive comfort one defined in EN 15251, category II).

User behaviour is taken into account by developing algorithms which simulate:

- the use of movable shadings by occupants in order to control visual discomfort
- the use of artificial lighting by occupants in response to different levels daylighting
- the use of operable windows in summer in response to temperature levels

Low energy Sustainable summer comfort solutions: case studies

One of the barriers to a wide diffusion of low energy concepts for summer comfort is a certain scarcity of well documented case studies. The project KeepCool aims at contributing to a better and large availability of data on buildings relying on the "sustainable summer comfort" concepts. We present here two case studies of office buildings in quite different climatic con-

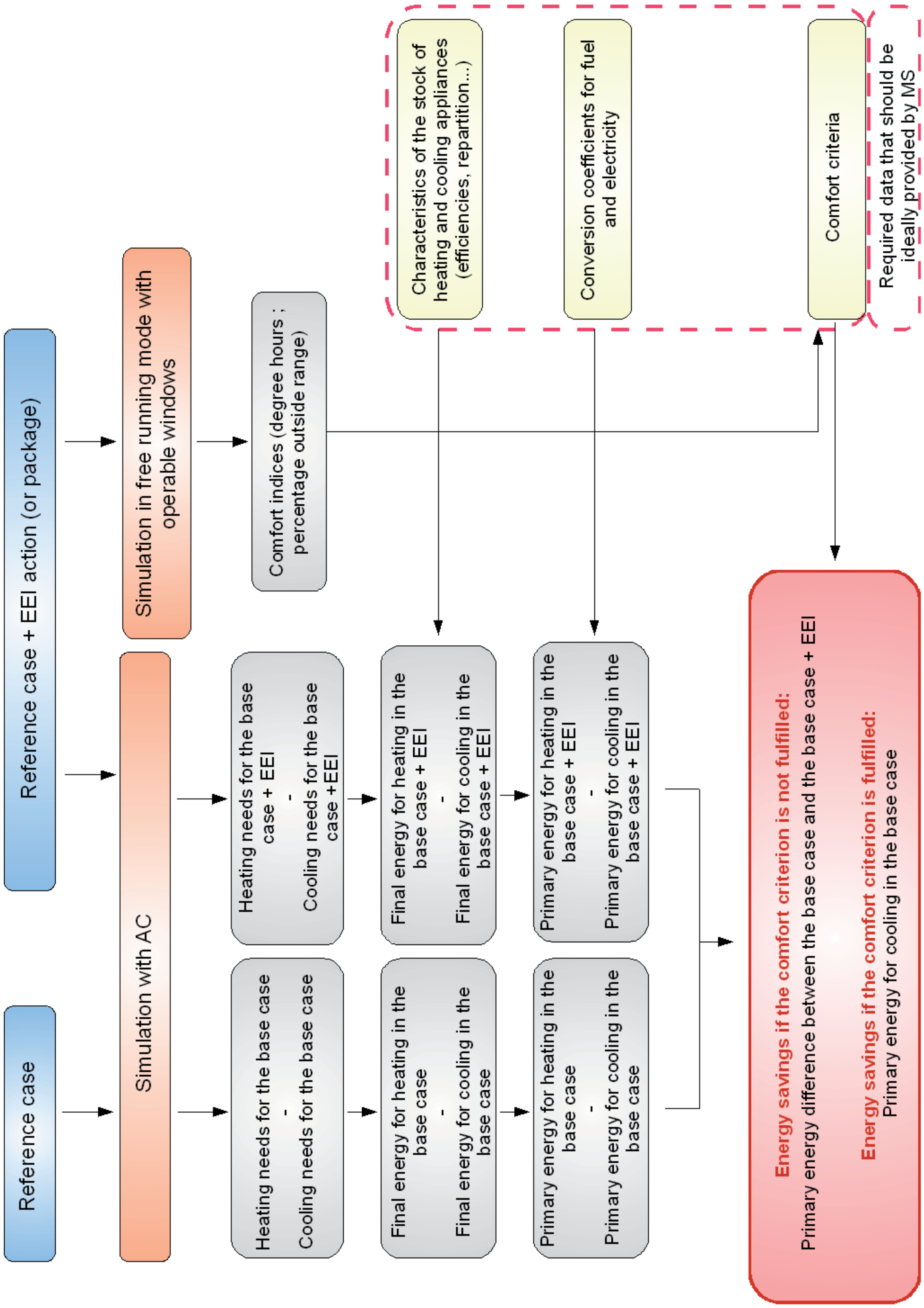

Figure 2. General methodology

Table 3. The main data for the Best Practice Project MIVA building

Year of construction	2003
Type of construction	Light outer construction with heavy components inside
Function	Office building plus a cefeteria and a loading/parking space inside
Location	Austria,48°05' north, 13°51' east, 370 m above sea level, countryside
Main technologies for cooling	Mass activation, night ventilation, water to ground heat exchanger,
Energy distribution system	Heating and cooling panels, floor heating
Heated/cooled building area	1215 m^2

ditions. Though they are new buildings and low energy summer comfort concepts have been an integral part of the energy concept since the beginning of the design process, we believe that:

- some of the techniques adopted here are suitable be implemented also in retrofit actions
- well designed and implemented techniques in new buildings, with expected performances consistently compared with monitoring results, can help gain new insight on performances, experience in correct implementation, and hence enhance chances of full success also in retrofit actions.

AUSTRIA: MIVA CHRISTOPHORUSHAUS OFFICE BUILDING

This project is of best practice character because of the very early integrated planning process with the planning team (architectures, energy engineers, civil engineers). Lower running costs for the building were achieved and the CO_2 emissions are 80% lower than those for a conventional office building. A commissioning process took place in the initial time of operation of the building in order to fine tune the operation.

The initiative of the project was of the building owner, who contacted AEE INTEC and asked for an expertise consultation before the project was started. AEE INTEC coordinated the entire planning process and carried out the energey calculations and optimisations. It was shown that such coordination with one partner acting as "energy party in charge" was of great importance for an innovative construction project. The financial planning of the project was done by the building owner, who aimed at applying sustainable energy technology and reaching a passive house standard.

The reduction of the energy demand for heating and cooling was a project requirement together with a sustainable and cost efficient energy supply system. Optimisation calculations were carried out for the building and considered improvements in the U-values of the glazed areas, application of thermal building mass, reduction of glazed areas in the atrium (up to 50%), application of solar protection glass and heat protection glass, avoidance of thermal bridges, reduction of air infiltration, optimised lighting concepts, optimised shading concepts, high efficient heat recovery application, application of night ventilation and optimisation of all HVAC equipment.

The shading devices and the lighting is operated through sensors at the work area, with the aim of optimal daylight utilisation. The conference rooms are equipped with CO_2 sensors via which the ventilation is regulated and is activated when the CO_2 level is higher than a set value (1,000 ppm). The ventilation and heating are deactivated on the weekends.

The energy supply is supervised via continous monitoring of all the systems.. The person in charge of the operation of the site is automatically informed with a warning message, in case the monitoring software detects any operation problem.

The applied passive cooling technologies are the following:

1. earth to water heat exchangers: they serve as both heat source (heating period) and cooling source (cooling period), see Figure 3. During the heating period a heat pump (43 kW and COP = 4,03) is used to achieve the necessary temperature level, while in summer a "direct cooling" strategy is realised through panels integrated in the building components, which are flown through with cold water coming directly from the ground heat exchangers.
2. night ventilation: in summer a natural air flow through the atrium during the nigh is used to extract thermal energy accumulated during the day. The ventilation of the office building is carried out with the means of two separated ventilation systems which in winter make use of heat recovery exchangers (78% recovery rate and 2,800 m^3/h nominal air flow) through a rotation heat exchanger. The ventilation of the seminar remises have an 86% heat recovery and a nominal air flow of 1,000 m^3/h.
3. heat storage mass: the storage mass of the building is the stabilising element of the room temperature. The upper 10 cm in the room are decisive for this effect. 100 tons of storage mass was included in the MIVA building.

Figure 4 shows how the mean indoor temperature in the different rooms and areas of the building vary with the mean outdoor temperature. The yellow marking indicates the comfort area for office working activities according to DIN (German) norms in force at the time of monitoring. The monitoring results show that the comfort parameter indoor temperature and humidity show good and constant values for the monitored period of two years.

Also the supply during the transition time function well and almost without any auxiliary primary energy supply (heat pump). This means that the heat recovery from the ventilation system and the "direct cooling" concept with the deep sonds are enough to keep the room climate at a comfortable level.

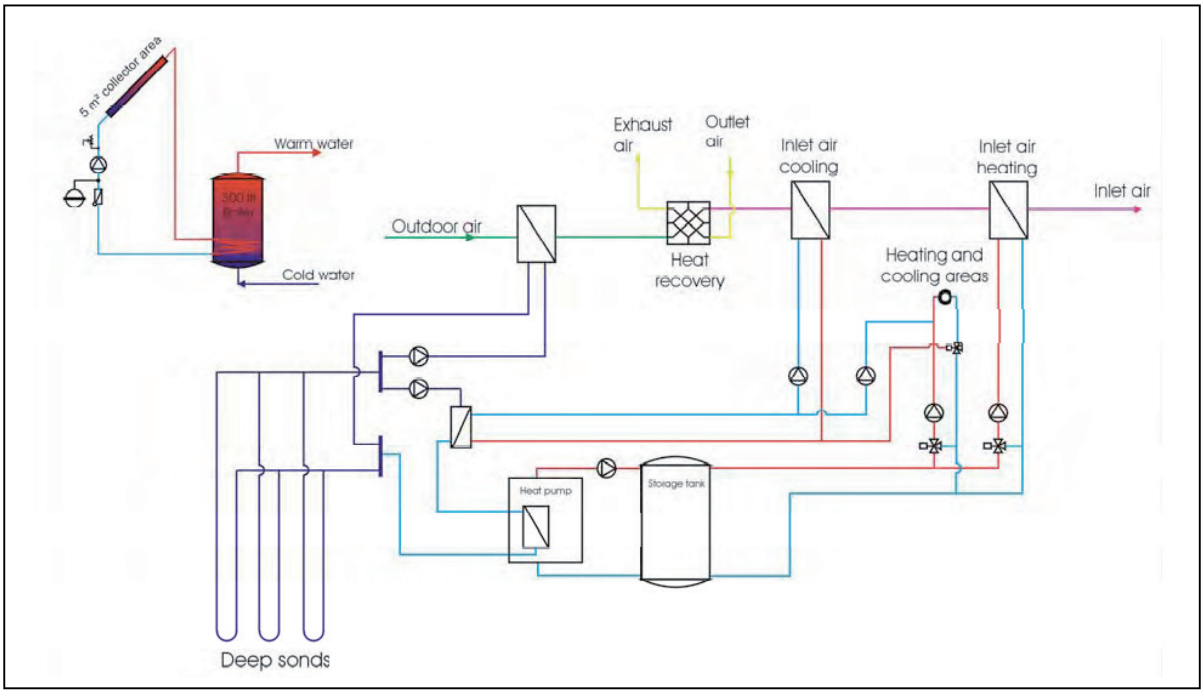

Figure 3. Plants logic

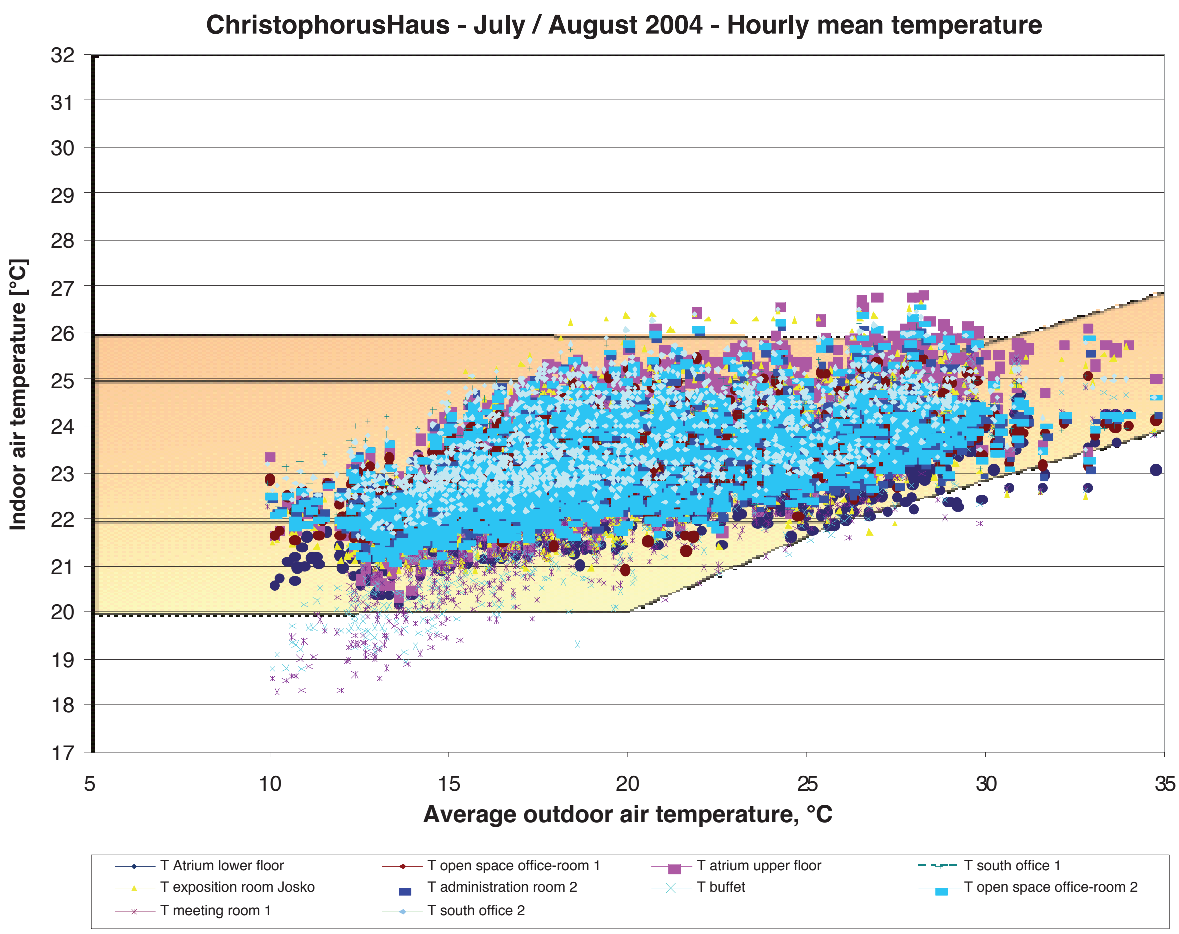

Figure 4. Mean indoor hourly temperature in different areas of the ChristophorusHaus building and the mean outdoor temperature – July/August 2004)

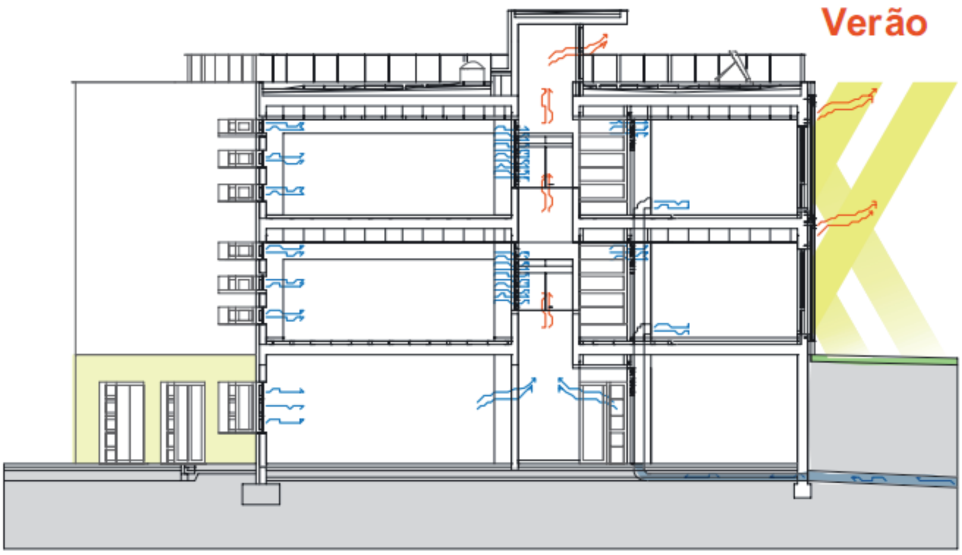

Fig. 6.Summer cooling strategies.

Figure 5. Edifício Solar XXI: South façade and scheme of summer cooling strategies, including ground exchanger. Source: INETI

Energy performance

During the cooling period the measured cooling demand was 6.4 kWh/m²a and the maximal cooling load was 11 W/m². The summer results can be seen as a successful integration of load reduction (day light controlled shading) and passive cooling (ground to water heat exchanger, night ventilation).

The heating demand was measured to 20 kWh/m²a and the maximal heat load was 13 W/m² for the winter operation.

PORTUGAL: EDIFICIO SOLAR XXI

The building is located inside the INETI campus in Lisbon and it is the new office premises for the Renewable Energy Department of INETI. "Edifício Solar XXI" shall operate comfortably as an office building, while being a demonstration project for building solar passive and active technologies. The building has a total habitable surface of 1,500 m² on three floors, one of them lying underground in the South façade. The space is used for office rooms, meeting rooms and laboratories.

This project shows that it is possible for a building office located in Lisbon (Mediterranean climate) to meet summer comfort objectives without active cooling systems. Technologies used for passive cooling addresses the main techniques available: sun protection, thermal mass, individual adaptation, earth cooling, ventilated façade and natural ventilation. It is also shows a remarkable integration of sustainable technologies like solar passive heating, passive cooling and active solar thermal and solar photovoltaic systems.

Passive cooling strategies in the "Edifício Solar XXI" building avoided the need to install a mechanical cooling system. These strategies are described as follows:

Optimisation of the building envelope

Externally applied thermal insulation (U-value façade: 0.5 W/m²K, roof: 0.3 W/m²K) avoids thermal bridges and allows the thermal use of the building mass. Double glazing with external movable Venetian blinds (solar factor of 0,04). With these measures, heat gains through opaque façades and roof are (i) reduced, (ii) stored in the mass of the building and (iii) released during the night to indoor spaces that can be sufficiently cooled down by natural ventilation.

Table 4. Main data for the Edificio Solar XXI building.

Year of construction	2004-2005
Type of construction	Heavy, concrete structure and brick walls
Function	Office building
Owner	INETI – National Institute for Engineering, Technology and Innovation
Design team	Helder Goncalves, Marcos Nogueira, et Al.
Location	Lisboa, Portugal,38°42' north, 9°5' west
Main technologies for cooling	Thermal insulation, mass activation, natural ventilation, ground exchanger, ventilated facade
Heated/cooled building area	1500 m^2

Reduction of internal heat loads by extended daylight use

In the central part of the building, there is a skylight that harnesses natural lighting for the three floors, as there are transparent elements between central corridor and adjacent rooms.

Natural ventilation

Two main techniques were applied:

- Ventilated façade: using the heat generated in the rear part of the photovoltaic panels, operating together with two openings in each room (at low and high height) to create a free convection air movement in the South façade;
- Stack effect: there are openings in the skylight and in the other parts of the building façade, to allow the night cooling ventilation.

Earth to air heat exchanger

It consists of 32 concrete buried pipes, 4,6 m underground, with 30 cm of diameter each, having a buried plenum 15 m away of the south façade of the building. The pipes take the outside air, cool it down, and conduct it into the building by a vertical distribution system (open "fresh air" system). In each room, there is an entrance for two pipes, that can be manually regulated, and a small fan for increasing the incoming air flow rate. This system can "explore" the temperature difference between outside air (in summer it can reach 30-35°C) and soil (14-18°C).

Individual adaptation

Users are allowed to change their clothes, to open or close windows and doors, to regulate the position of the Venetian blind and to regulate the air flow rate coming into their room from the earth tubes.

Monitoring

Monitoring of energy performances is ongoing. The two summers of 2006 and 2007 outdoor air temperatures were quite high for Lisbon, above 35°C achieving even 40°C during day time. In these two summers the mean temperatures inside the building varies between 24°C and 25.4°C, for mean maximum temperatures from 26.4°C up to 28.1°C. These temperatures correspond to the rooms in the south part of the building which are the hottest one, in the north part of the building, like in winter a difference in these location can achieve 2°C (Gonçalves and others 2008).

Comfort policies to support Sustainable summer comfort solutions: case studies

The Directive on Energy End-use Efficiency and Energy Services (EEE- ESD), Article 5, requires the member states' public sector bodies and agencies to play an exemplary role in improving energy efficiency. As public authorities represent a considerable market power, this may support the transformation of the markets towards energy efficiency.

This section aims at describing initiatives taken by public authorities or other public building owners such as universities or banks to improve energy efficiency in their buildings and to introduce sustainable summer comfort solutions. The KC2 complete report contains examples from the US, Italy, Japan, the UK, France and the United Nations.

We will report in this paper a synthesis of the comfort policies adopted in three most significant cases, which apply most of the ten steps of KeepCool process towards sustainable cooling

"Code of Conduct" at Sidney University (Australia, 1999 onward)

The University has had an Air Conditioning Policy in place since 1986 which was revised in September 1997.

The 1999 document states: "Comfort air conditioning in University spaces set aside for University purposes (not leased or occupied by external organizations) will be approved only for those spaces which would otherwise have intolerable conditions for the occupants, and special areas where controlled environment is judged as being necessary. This is provided passive thermal control, such as shading and insulation, is not effective or appropriate, either on architectural or structural grounds.

Where comfort air conditioning is judged to be necessary, careful consideration will be given to installing systems with the capacity to reduce indoor room temperatures to a maximum of approximately 5°C to 9°C below ambient, with a minimum set point of 27°C.

"Code of conduct" at Middlebury College (Vermont, USA, 2003 onward)

In the "code of conduct" at Middlebury College (Vermont, USA), the college:

- commits to give priority to heat load reducing mechanisms before introducing mechanical cooling;
- encourages individual adaptation during heat wave periods (e.g. relaxed dress codes, use of ceiling fans, adaptation of

the working schedule to avoid working during hotter hours etc.);

- gives exact guidance on the use of mechanically cooled spaces.

In the official documents of the College it is in fact stated: "The college's priority for the cooling of spaces is to employ natural ventilation techniques and behavior changes whenever possible. Supplemental use of mechanical devices will be considered only when absolutely necessary. Through effective new building design and retrofits to existing structures - via building orientation, well insulated envelopes, and devices to limit summer solar radiation intrusion (e.g. window shades) the College is committed to minimizing the need for future mechanical cooling systems".

During sustained period of high heat and humidity (defined here as two or more consecutive days of outside temperatures above 32°C and relative humidity of over 60%) certain measures may have to be taken

- a "relaxed dress code" will be in effect. All college staff, as well as faculty and students are encouraged to wear light, well ventilated, appropriate attire.
- wherever possible, *flexible work schedules* should be implemented, allowing employees to report to work 1-2 hours early and leaving earlier to avoid the maximum heat period during the middle and late afternoon.
- Wherever it is not imperative that staff remain at their desks at all times, supervisors will permit them to *take their work and move to a "cool area"* a naturally cooled or air conditioned space either in the same building or in a proximate one. Similar "cool areas" will be established in, or proximate to, student dormitories and classroom/office buildings.
- *Employees working in spaces that cannot be cooled by using natural cooling methods and fans* (e.g. because they have no windows or no or inadequate cross- ventilation) and where installing air conditioning units is not a reasonable option *will be permitted to take an extra morning and afternoon break in a "cool area"*. On rare and extreme occasions, should the temperature in such a space rise to a point where productive work is no longer possible, and the worker(s) impacted cannot move to cooler work areas, supervisors should dismiss affected employee(s) after midday
- all offices that are not air conditioned will be supplied efficient floor, window, oscillating, and/or ceiling fans, as well as blinds or shades upon request. Facilities Management will determine which cooling method is most efficient for each space.

"Coolbiz" and "Warmbiz" Campaigns of the Japanese Government (Japan, 2005)

- In 2005, the Japanese government launched a nationwide campaign called "Team Minus 6%" to raise awareness of global warming. The goal is to use team work to meet the minus 6% reduction commitment stipulated in the Kyoto Protocol.
- In the summer of 2005, then Prime Minister, Koizumi Jun'ichiro, appealed to business leaders to allow office workers to remove ties and jackets, and to work in short-sleeve shirts from June to September. By removing jackets and neckties, body temperature is reduced by up to 2°C. With this casual dress code, the office can then reduce the air conditioning and raise the room temperature up to 28°C. Prime Minister Koizumi and his cabinet led by example and took off their neckties and jackets during the first Cool Biz campaign in summer 2005. Surprisingly, the "Cool Biz" dress style has become a fashion trend in Japan during the summer season. http://www.team-6.jp/english/index.html
- Complementarily Warm Biz, encourages offices to keep the heating temperature at 20°C in order to save energy during winter.

Conclusions

Energy consumption for space cooling is expected to grow rapidly in the next years in Europe, both in new and existing buildings.

As for existing buildings this paper reports the methodology and initial efforts to evaluate the savings of a number of retrofit actions on existing buildings and to include some relevant occupant behaviour patterns. The evaluation aims, inter alia, to deliver saving estimates to be used in the context of the National Energy Efficiency Plans.

For new buildings two examples in a central and south European climates are presented, that rely on envelope and passive strategies in order to deliver summer comfort to occupants. Though they are new buildings and low energy summer comfort concepts have been an integral part of the energy concept since the beginning of the design process, the authors argue that some of the techniques adopted here are suitable be implemented also in retrofit actions and that well designed and implemented techniques in new buildings, with expected performances consistently compared with monitoring results can help gain new insight on performances, experience in correct implementation, and hence enhance chances of full success also in retrofit actions.

Finally examples are given of "comfort codes of conduct" that systematically take advantage of behaviour choices in order to improve comfort and take stock of opportunities of flexibility in the use of buildings, both new and existing.

It is probably a combination of actions on existing buildings, guidelines and experience in the design of new buildings and well thought behavioural choices that can lead to "sustainable summer comfort". Further research and review work in these three directions is ongoing in the IEE project KeepCool2.

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