Principles and standards for sustainable summer comfort

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Abstract

Recent studies predict a dramatic increase of cooling energy demand in Europe, despite the available knowledge and technologies of passive cooling. The international project KeepCool addressed this gap, searching for intelligent ways to promote the market penetration of passive cooling technologies and a new definition of sustainable summer comfort based on ten steps. The project tailored the available information into a toolkit for building owners, planners and building users. In the eight participating countries, we explored various marketing strategies to reach these target groups, and uncovered four main barriers for the broad market implementation of sustainable summer comfort: outdated rules of thumb in building and plant design, remuneration schemes for planners and designers without incentives for integral planning, building codes concentrating on winter requirements, and the scattered supplier industry for passive solutions. One step towards overcoming these barriers is the adoption of the Adaptive Comfort Model in the European Standard EN 15251. The paper will present the evidence on which its provisions are based (focusing on thermal comfort) and the advantages they present for those concerned to design buildings which use the minimum of energy.

Introduction

Despite the available knowledge and technologies of low energy and passive cooling, cooling energy consumption is dramatically increasing in Europe. The studies EECCAC and EERAC predict a four-fold growth in air-conditioned space between 1990 and 2020 (Adnot et al, 1999; 2003). The IEA Future Building Forum named cooling as one of the fastest growing sources of new energy demand (International Energy Agency, 2004).

The preamble of the European Energy Performance of Buildings Directive (EPBD) states: "Recent years have seen a rise in the number of air-conditioning systems in southern European countries. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in those countries. 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).

In order to address the gap between available knowledge and practice, the international project KeepCool was initiated in early 2005. The overall goal of the project was to facilitate market penetration of sustainable cooling approaches and technologies in the participating countries, and implement activities that prevent a further increase of energy consumption for cooling in Europe. We addressed both newly constructed and existing service buildings in the public and private sector. Since the building owners are the driving force in the investment process, the project focused 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 aimed at supporting the cooperation between suppliers and ensuring the link to norms and policy instruments that might support sustainable summer comfort. KeepCool was supported by the European Commission through the Intelligent Energy Europe programme.

Toolkit for Sustainable Summer Comfort

We collected the available information on the state of the art in passive cooling technologies. Beside these technology profiles, we also analysed the national comfort legislation in the participating countries, and described 13 Best Practice Projects in English and 16 others in national languages. Further, a list of experts and suppliers of passive cooling technologies was prepared for each participating country.

In order to make all this information usable for building owners and planners, we processed all information material into an online toolkit for building owners and other target groups (see *Figure 1*). This toolkit is not only a new resource base for passive cooling. It combines our approach for sustainable summer comfort with the complex set of roles the different actors take when constructing, using, operating or maintaining a building.

Figure 1. The KeepCool Toolkit, online at www.keepcool.info.

As investors and decision-makers, **building owners** can set up requirements for buildings in general and specific targets on cooling solutions. Thus, they are able to set the framework for the planning process. Building owners are connected with the **building users** and with the **operation and maintenance (O&M) staff** via contractual agreements. These contracts might also contain specifications on comfort levels or operational prescriptions. Building users influence both the performance of the building (choice of room temperatures, operation of windows, contribution to internal heat loads) and the energy performance through rental agreements. O&M staff need information on how sustainable cooling is operated, and are also important as a link to the building users. For complex projects, building owners are increasingly accompanied by **building consultants** of different fields (see *Figure 2*).

We developed a logical pathway to reduce cooling energy demand in buildings, towards a target that we call sustainable summer comfort. Sustainable summer comfort can be defined as "achieving good summer comfort conditions with no or

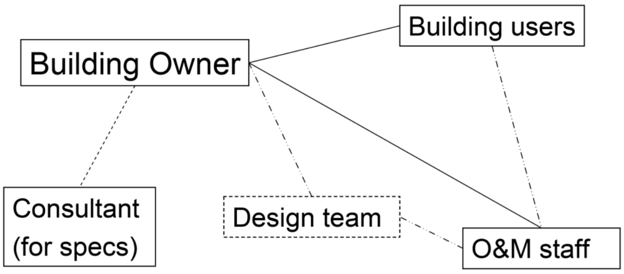

Figure 2. Relationships between actors in service buildings: Contractual agreements between building owners, building users and the O&M staff (full lines). Advice from consultants to the building owner (dashed lines). Informal communication between most target groups (semi-dashed lines).

limited use of resource energy[1] and through the use of environmentally non-harmful materials" (Varga & Pagliano, 2006, p. 3). 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). Not all steps and actions will be available in a specific situation to the owner/designer, but our suggestion is to follow this path and closely analyse the possibilities for action in a given situation for each step.

In the following, we present the ten steps to achieve sustainable summer comfort, as they are presented in the toolkit as well as in one of our previous papers (Varga & Pagliano, 2006). Technology profiles to almost all steps, and the above mentioned reports on best practice, legislation and market analysis are available in the toolkit at the project's Website www.keepcool.info, as well as in the project's final report (Varga et al, 2007).

1. Define the thermal comfort objectives explicitly, using the Adaptive Comfort model where possible

Mostly, regulations require keeping upright a constant indoor temperature, regardless of the outdoor conditions. These prescriptions come sometimes from a unduly rigid interpretation of the underlying comfort 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 and the environment (steady-state). The surveys for constructing a correlation between the above variables and the comfort vote were performed in climate chamber experiments. Care should be taken in order to apply the model only within its validity limits, as prescribed in ISO 7730 (issued in 1994 and revised in 2005).

1. Resource energy is defined as "energy taken from a source which is depleted by extraction (e.g., fossil fuels)" in the CEN document in preparation of a norm on "Heating systems in buildings — Energy performance of buildings — Overall energy use, primary energy and CO_2 emissions"

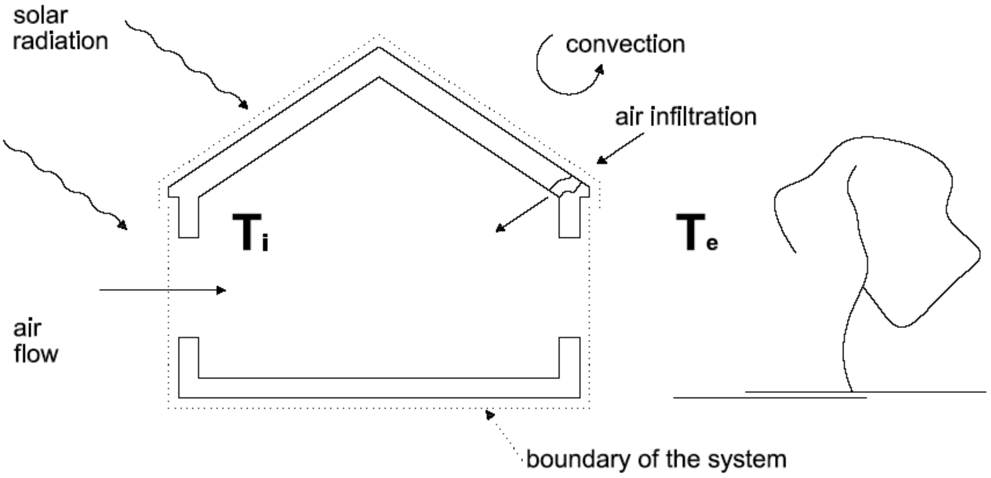

Figure 3: Thermal energy flows though the boundary separating the building and its environment because of absorption of solar radiation, convection exchanges with the atmosphere, air infiltration and air flows through cracks and openings.

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 outside temperature; in particular, it has a correlation with the average external temperature in the last few days. The correlation is derived from interviews to occupants of real, free running buildings (the results and analysis of these interviews are presented in the SCATs database and the ASHRAE RP 884 database).

The Adaptive model of comfort has wide implications on the application of passive cooling methods and energy use for cooling. As the indoor comfort temperature varies in time in correlation with the average of the outside temperature, the difference between the two temperatures tend to be lower, and consequently cooling loads tend to be lower than in buildings with fixed temperature set points. Further, the slightly fluctuating indoor comfort temperature under the Adaptive Comfort Model is more likely to be achieved by passive cooling methods than the fixed temperature set point derived from the Fanger model and hence does not put passive architecture at a disadvantage.

The Adaptive Comfort Model and the way it has been included into the European standard EN 15251 is described in detail below in this article.

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 choice of materials and finishing with low values of solar absorbance for 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 solar radiation and of the difference between outside air temperature and inside air temperature (see *Figure 3*). 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.

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 office equipment2 and by ensuring that all systems are turned to stand-by or off when not in use. The internal gains due to a high presence of occupants (e.g. in conference rooms etc.) need to be duly taken into account as for the possible need of active cooling in this case.

2. As an example power requirement of different laser printer models can vary from 480 to 100 W while printing, and their stand-by consumption can vary from 90 to 20 W. A ink-jet printer may consume 15 W while printing and 5 W in stand-by mode.

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".

ASHRAE 55-2004 and ISO 7730-2005 state that increased air velocity can be used to offset the warmth sensation caused by increased temperature. Under summer conditions, the temperature can be increased above the level allowed for comfort if a means is provided to also elevate the air velocity. The adjustments proposed to the upper limit of the comfort zone determined with the PMV model reach 2.5 °C with air velocity 0.8 m/s. ISO 7730-2005 also contains a list of insulation values of furniture, e.g. types of chairs and armchairs.

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 sink where to discharge heat removed from the building, open groundwater or surface water systems, 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: "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 (…)" (Givoni, 1991, p. 177).

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 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 drive towards 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 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 only 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 assess 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).

Marketing and dissemination for sustainable summer comfort

In order to achieve real change of construction practice, marketing activities must go beyond pure dissemination and information transfer. They must include also activities related to "market transformation" by bringing together the relevant actors and building up a structured supplier/customer dialogue in the scattered market of passive cooling.

The main dissemination activity in the project was therefore direct advice to building owners and the other target groups. In five countries, this advice resulted in pilot projects in both new construction and refurbishment that will apply our approach of sustainable summer comfort. In three countries, we conducted architecture competitions, and two countries worked with the suppliers of sustainable comfort solutions, providing a meeting point to start cooperation. Beside direct advice, awareness building activities were conducted in all participating countries. The project team organised workshops, and was present at events and fairs of the target groups. In addition, we were present in daily and specialised media, and built up several websites in English and in national languages.

International meetings were a good concentration point to scrutinise the approach to Sustainable Summer Comfort. Specific results of the KeepCool project were presented and discussed at the following international conferences: At the 9. International Passive House Conference 2005 (oral presentation), at PALENC 2005 (Pagliano & Zangheri, 2005), eceee 2005 (informal session on summer comfort), IEECB 2006 (Varga & Pagliano, 2006), NCEUB 2006 (informal discussions) and finally at EPIC 2006 (Varga et al., 2006; Nicol & Pagliano, 2006).

Parallel to these activities, KeepCool was invited to provide input to the EuroHeat project coordinated by the WHO. The results of the project are further disseminated by the "Network for promotion of Eco-Building technologies, small polygeneration and renewable heating and cooling technologies for buildings" of the ProEcoPolyNet project under financial support of the European Commission's Sixth Framework Programme. In addition, a follow-up project named "KeepCool II" is planned to tackle in particular the following market barriers that prevent the transformation of the present planning and tendering culture from supplying and asking for "cooling" to supplying and asking for "comfort":

- Outdated rules of thumb in building envelope and cooling systems design;
- Remuneration schemes for planners and designers;
- Building codes concentrating on winter requirements;
- Scattered supplier industry for passive solutions.

In spite of better standards and design guidelines, often planners use outdated rules of thumb for design of the building envelope and the plants. In addition, the remuneration schemes for planners and designers do not support integrated planning; frequently the payment is mainly related to the size of the HVAC equipment built into a building, rather than to its performances. Furthermore, the building codes mostly concentrate on winter requirements, leaving summer energy efficiency for "green" architects and planners. And finally, as passive solutions are mostly a combination of different strategies, their supplier industry is scattered: suppliers are from different branches, and are less well organised than other industries in the construction sector. In order to be successful, future actions must tackle these four barriers: there is a great need for incentives for planners, architects and engineers towards integrated planning, for stronger summer requirements in national building codes, for wider diffusion of correct design rules for envelope and cooling systems and for a better cooperation between suppliers of components, systems, planners, architects and procurement specialists.

The adaptive comfort model in the new standard EN 15251

THE ADAPTIVE APPROACH TO THERMAL COMFORT

The Adaptive Approach to thermal comfort (Humphreys and Nicol, 1998) has been developed from field-studies of people in daily life. While lacking the rigour of laboratory experiments, field studies have a more immediate relevance to ordinary living conditions (deDear 1998; Humphreys, 1975; Auliciems, 1981). The adaptive method is a behavioural approach, and rests on the observation that people in daily life are not passive in relation to their environment, but tend to make themselves comfortable, by making adjustments (adaptations) to their clothing, activity and posture, as well as to their thermal environment. The results and analysis of the interviews to people in real buildings, free floating, are presented in the SCAT database and the ASHRAE RP884 database.

Over time people tend to become well-adapted to thermal environments they are used to, and to find them comfortable. Adaptation is assisted by the provision of control over the thermal environment to give people the opportunity to adapt. This 'adaptive opportunity' (Baker and Standeven 1996) may be provided, for instance, by fans or openable windows in summertime or by temperature controls in winter. Dress codes will also have consequences for thermal design, for services provision, and consequently for energy consumption. A control band of ± 2 K should be sufficient to accommodate the great majority of people (Nicol and Humphreys 2007).

These customary temperatures (the 'comfort temperatures') are not fixed, but are subject to gradual drift in response to changes in both outdoor and indoor temperature, and are modified by climate and social custom. Field research can indicate the extent and rapidity of adaptation, and hence of the temperature drifts that are acceptable. During any working day it is desirable that the temperature during occupied hours in any day should vary little from the customary temperature. Temperature drifts much more than ± 2 K in any day would be likely to attract attention and might cause discomfort.

Clothing and other adjustments in response to day-on-day changes in temperature, will occur when a building is responding to weather and seasonal changes These will occur quite gradually (Humphreys 1979; Nicol and Raja 1996; Morgan, deDear & Brager, 2002), and can take a week or so to complete. So it is desirable that the day-to-day change in mean indoor operative temperature during occupied hours should not occur too quickly for the adaptive processes to keep pace.

During the summer months many buildings in Europe are free-running (i.e. not heated or cooled). The temperatures in such buildings will change according to the weather outdoors, as will the clothing of the occupants. Even in air-conditioned buildings the clothing has been found to change according to the weather (deDear and Brager 2002). As a result the temperature people find comfortable indoors also changes with the weather (Humphreys 1981). Thus the temperature people find comfortable can vary quite considerably depending on the climate, but any change should occur sufficiently slowly to give building occupants time to adapt.

COMFORT IN BUILDINGS

In buildings which are in free-running (FR) mode indoor conditions will follow those outdoors but will be modified to a greater or lesser extent by the physical characteristics of the building and the use which building occupants make of the controls (windows, shading devices, fans etc) which are available to them. In a successful building these actions, together with the changes which the occupants make to their own requirements – mainly through clothing changes – mean that occupants are able to remain comfortable most of the time. The function of a standard is to define the indoor conditions which occupants will find acceptable for any given outdoor condition.

Humphreys (1979) showed that the temperature which occupants of FR buildings find comfortable is linearly related to the monthly mean of the outdoor temperature. Other researchers have since found similar results (e.g. deDear and Brager 2002). The SCATS survey based in 5 European Countries has increased the accuracy and applicability of the model by showing that it is the running mean of the daily mean outdoor temperatures which correlates best with indoor comfort temperature (McCartney and Nicol, 2002) and that for free-running European offices the linear relationship is:

$$T_c = 0.33\,T_{rm} + 18.8$$

Where T_c is the optimal operative temperature for comfort and T_{rm} is the running mean of the daily mean outdoor temperature. Full definitions of the running mean temperature are given in McCartney and Nicol (2002) and in chapter 1 (section 1.6) of the CIBSE Guide A (2006). It should be mentioned that this relationship strictly applies to the subjects who took part in the SCATs surveys and the buildings they occupied, but it closely matches the relationship presented by deDear and Brager from their survey of buildings throughout the world (ASHRAE database rp884) and this suggests that it has general applicability.

In Figures 4 and 5 below we present for two climates and typical years the evolution of external air temperature and the indoor operative comfort temperatures.

Adaptive Operative Comfort Temperature is calculated according to Equation 1; Fanger Operative Comfort Temperature is calculated using the formulas presented in ISO 7730 and assuming the following values of the input variables:

- thermal resistance of the clothing (Clo) = 0.5 clo
- metabolic rate (Met) = 1.4 met
- air velocity (V) = 0.15 m/s
- relative humidity (Ur) = 50 %

This corresponds to general practice, where building planners have to make an assumption on those values adopting an average reasonable value for the entire season, and hence obtaining a constant value for the Comfort Temperature.

Having defined an optimal comfort temperature T_c, based on the interviews, the question arises of how far the temperature of a space can deviate from T_c before discomfort will occur. Nicol and Humphreys (2007) have analysed the data from SCATs to show that 'the temperatures at which discomfort will not be unduly intrusive are up to ± 2 K above or below the appropriate comfort temperature', which makes this a sensible limit for a comfort zone.

EN 15251 AND TEMPERATURE LIMITS IN FREE RUNNING BUILDINGS

The preamble of the European Energy Performance of Buildings Directive (EPBD) states: "(...) the displaying of officially recommended indoor temperatures, together with the actual measured temperature, should discourage the misuse of heating, air-conditioning and ventilation systems. This should contribute to avoiding unnecessary use of energy and to safeguarding comfortable indoor climatic conditions (thermal comfort) in relation to the outside temperature." (European Communities, 2003, p. L1/66). Ensuring that both energy savings and a good indoor environment are targeted is essential (Varga and Pagliano 2006). The European Standard EN 15251 "Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics" seeks to define minimum standards for the internal environment in buildings to complement the EPBD. A major consideration of the EN is to ensure a correct definition of thermal comfort.

The International Standard EN ISO 7730-2005 makes no allowance for differences in comfort conditions in naturally ventilated (NV) and mechanically cooled (AC) buildings. For this reason it is important that EN 15251 embodies the latest thinking about comfort in the variable conditions of real NV buildings, allowing designers to take advantage of occupants' natural ability to adapt conditions to their liking. This not only optimises the interaction between occupants and the building to ensure comfort but also enables designers to maximise energy saving by allowing indoor conditions to track those out of doors. EN 15251 makes a distinction between buildings which are heated and/or cooled (HC) and those which are free running (FR). Thus NV buildings will be HC during the heating season and FR during the summer; AC buildings are HC through-out the year. In Standard EN 15251, the comfort zone for HC buildings is defined as in EN ISO 7730 (2006).

EN 15251 uses the results of the SCATs survey to define the limits of temperatures in buildings divided into categories defined as shown in Table 1. The width of the acceptable zones allowed in each category is shown as a deviation from the value which is calculated from Equation 1. The applicability of the zones is assumed to be for values of T_{rm} between 10 °C and 30 °C. EN 15251 has also introduced an allowance for air movement which can mean that the upper limit of acceptable temperature can be raised when substantial air movement is present such as might occur when a fan is in use. Figure 6 shows the design values for the four categories in NV buildings. For more details, especially for noise levels, air quality and the temperature limits for AC buildings, see Olesen (2007).

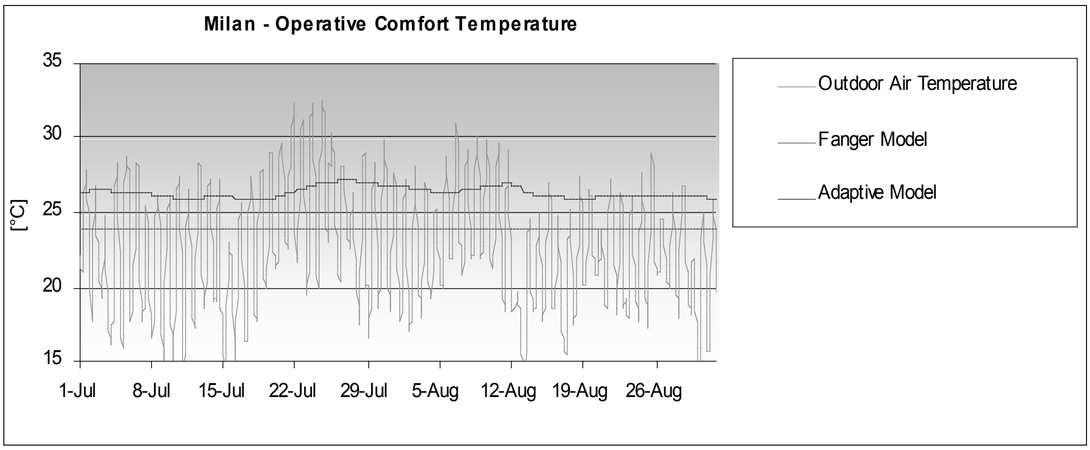

Figure 4: Adaptive Operative Comfort Temperature and Fanger Operative Comfort Temperature for standard summer outdoor temperatures in Milan, Italy

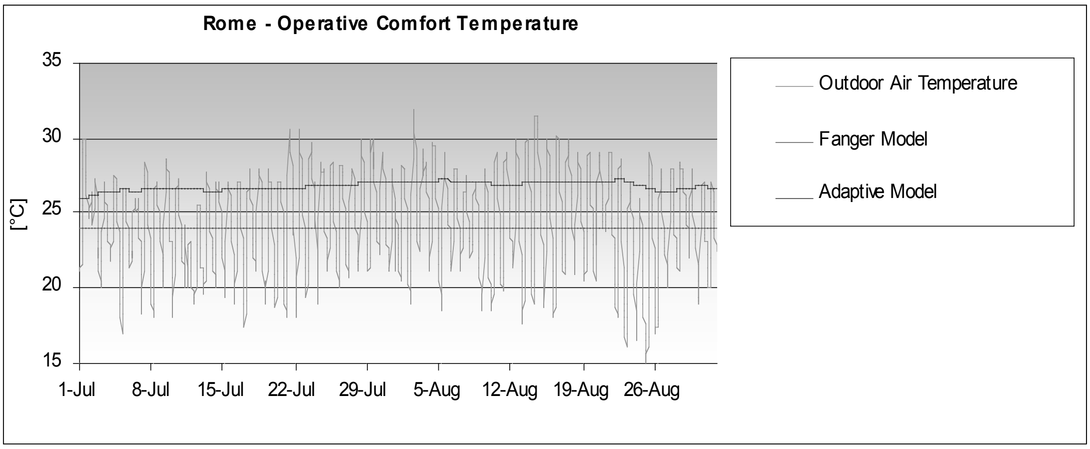

Figure 5: Adaptive Operative Comfort Temperature and Fanger Operative Comfort Temperature for standard summer outdoor temperatures in Rome, Italy

Table 1: Suggested applicability of the categories and their associated acceptable temperature ranges.

Category	Explanation	Suggested acceptable range
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	± 2K
II	Normal expectation (for new buildings and renovations)	± 3K
III	A moderate expectation (used for existing buildings)	± 4K
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	

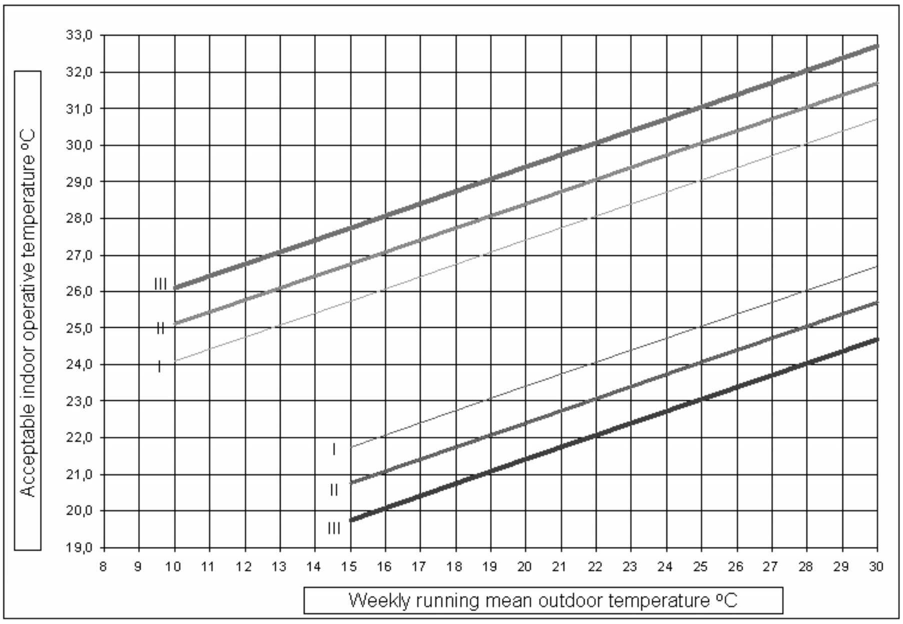

***Figure 6: Design values for the indoor operative temperature for buildings without mechanical cooling systems** as a function of the exponentially weighted running mean of the outdoor temperature (McCartney and Nicol, 2002, cited in Olesen, 2007).*

EVALUATION OF THERMAL CONDITIONS FOR COMPLIANCE WITH EN 15251

There are two methods suggested in the EN for evaluating the thermal comfort conditions:

1. Percentage outside range: the proportion of the occupied hours during which the temperature lies outside the acceptable zone.
2. Degree hours criterion: The time during which the actual operative temperature exceeds the specified range during occupied hours is weighted by a factor depending on the number of degrees by which the range has been exceeded

Acceptability of the space on the 'percentage' criterion is on the basis that the temperature in the rooms representing 95 % of the occupied space is not more than 3 % (or 5 % - to be decided) of the occupied hours a day, week, month or year, outside the limits of the specified category. Acceptability for the degree hours criterion are still to be decided. Subjective evaluation may also be accepted in existing buildings and methods for evaluating this are given.

Conclusions

The KeepCool project provided a good base for the market transformation from "cooling" to "summer comfort", that is from demand for an energy-using action to demand for a service. It brought together the results of many research projects into one consistent approach for sustainable summer comfort, and developed understandable information material for the most important target groups. In addition, it started with market implementation in eight European countries, delivering important experience on the barriers on the market.

Future actions in the field can use the results of our project for further market transformation activities: they can continue to tackle the identified market barriers, and by doing this, they can employ the dissemination principles that proved to be most successful during the course of KeepCool. A great opportunity to overcome the four identified barriers is given in the relevant EU Directives: in its introduction, the EPBD is explicitly calling for "strategies which enhance the thermal performance of buildings in the summer period" (European Communities, 2003, p. L1/66). In addition, the new Directive on Energy End-Use Efficiency and Energy Services (EEE-ESD) is setting energy saving targets for the European Union and the Member States, and requires an Energy Efficiency Action Plan (EEAP) as well as energy efficiency criteria in public procurement schemes from each Member State (European Communities, 2006). Both instruments allow for the broad implementation of measures that help to consolidate the passive cooling market, to support integrated planning and to make use of the newest standards in the design of cooling equipment. In turn, Sustainable Summer Comfort seems to be a very effective means to fulfil the requirements of the EEE-ESD, as it leads to a considerable and long lasting reduction of the energy (and especially the peak energy) consumption of buildings.

First steps towards this goal have been made with the proposed new European Standard EN 15251: It has been framed to allow the natural variability of the indoor climate in free running buildings to be matched to the natural ability of people in well designed buildings with adequate occupant control, to change their room conditions to suit their needs. This will mean that buildings can be designed which are both comfortable and can make full use of passive, low energy cooling and heating technologies.

References

Adnot, J. et al. (1999). *Energy Efficiency of Room Air-Conditioners (EERAC).* Study for the Directorate-General for Energy (DGXVII). of the Commission of the European Communities. Final report.

Adnot, J. et al. (2003). *Energy Efficiency and Certification of Central Air Conditioners (EECCAC).* Study for the D.G. Transportation-Energy (DGTREN) of the Commission of the E.U., Final report.

Auliciems, A. (1981). Towards a psycho-physiological model of thermal perception. *International Journal of Biometeorology 25,* 109-122.

Baker, N. V. & Standeven, M. A. (1996). Thermal comfort in free-running buildings. *Energy and Buildings*, *23,* 175-182.

CIBSE (2006). *Guide A: Environmental Design.* London, Chartered Institution of Building Services Engineers.

deDear, R. J. (1998). A Global database of thermal comfort field experiments. *ASHRAE Transactions 104*(1), 1141-1152.

deDear, R.J. & Brager, G.S. (2002). Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and Buildings 34,* 549-561.

EN ISO 7730 (2006). Moderate *thermal environments- determination of the PMV and PPD indices and specification of the conditions for thermal comfort.* ISO, Geneva.

European Communities (2003). Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. *Official Journal of the European Communities, 4.1.2003,* L1/65-L1/71.

European Communities (2006). Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC. *Official Journal of the European Union, 27.4.2006,* L114/64-L114/85.

Fanger, P. O. (1970). *Thermal Comfort.* Copenhagen: Danish Technical Press.

Givoni, B. (1991). Performance and applicability of passive and low-energy cooling systems. *Energy and Buildings, 17,* 177-199

Humphreys, M. A. (1975). Field studies of thermal comfort compared and applied: *J. Inst. Heat. & Vent. Eng. 44,* 5-27.

Humphreys, M. A. (1979). The influence of season and ambient temperature on human clothing behaviour. In P. O. Fanger & O. Valbjorn (eds.): *Indoor Climate*. Copenhagen: Danish Building Research.

Humphreys, M. A. (1981). The dependence of comfortable temperature upon indoor and outdoor climate. In K. Cena & J. A. Clark (eds.): *Bioengineering, Thermal Physiology and Comfort.* Amsterdam: Elsevier

Humphreys, M. A. & Nicol, J. F. (1998). Understanding the adaptive approach to thermal comfort. *ASHRAE Transactions 104*(1), 991-1004.

International Energy Agency. (2004). *Cooling Buildings in a Warming Climate.* IEA Future Building Forum, Sophia Antipolis, France, 21-22 June, 2004.

McCartney, K. J. & Nicol J. F. (2002). Developing an adaptive control algorithm for Europe: Results of the SCATs project. *Energy and Buildings 34,* 623-635.

Morgan, C. A., deDear, R. & Brager, G. (2002). Climate Clothing and adaptation in the built environment. In H. Levin (ed.): *Indoor Air 2002: Proceedings of the 9th International Conference on Indoor Air Quality and Climate* (Vol. 5, pp. 98-103). Santa Cruz, USA, Indoor Air 2002.

Nicol, J. F. & Humphreys, M. A. (1972). Thermal comfort as part of a self-regulating system, in: *Proceedings of the CIB*

Symposium on Thermal Comfort. Watford, UK: Building Research Establishment.

Nicol, J. F. & Humphreys, M. A. (2007). Maximum temperatures in European office buildings to avoid heat discomfort. *Solar Energy Journal,* (available online 09/06)

Nicol, J. F. & Pagliano, L. (2006). *Allowing for thermal comfort in free-running buildings in the new standard prEN 15251.* Paper presented at the EPIC 2006 AIVC, the 4th European Conference on Energy Performance & Indoor Climate in Buildings: Technologies & Sustainable Policies for a Radical Decrease of the Energy Consumption in Buildings, Lyon, France, 20-22 November 2006.

Nicol, J. F. & Raja, I. (1996) *Thermal comfort, time and posture: exploratory studies in the nature of adaptive thermal comfort*. School of Architecture, Oxford Brookes University.

Olesen, B. W. (2007). The philosophy behind EN 15251: Indoor Environmental Criteria for Design and Calculation of Energy Performance of Buildings. *Energy and Buildings.* (Available online 7 February 2007).

Pagliano, L. & Zangheri, P. (2005). *Climate optimised building parameters for low energy summer comfort under a discomfort index.* Paper presented at the International Conference Passive and Low Energy Cooling for the Built Environment (PALENC 2005), Santorini, Greece, 19-21 May 2005.

Varga, M. & Pagliano, L. (2006). *Reducing cooling energy demand in service buildings.* Paper presented at the International Conference Improving Energy Efficiency in Commercial Buildings (IEECB'06), Frankfurt, Germany, 26 - 27 April 2006.

Varga, M., Bangens, L., Cavelius, R., Isaksson, C., Laia, C., Leutgöb, K., Lopes, C., Martinez Davison, J., Nicol, J. F., Pagliano, L., Perednis, E., Read, G. E. F., & Zangheri, P. (2006). *KeepCool: Promoting the market penetration of sustainable summer comfort.* Paper presented at the EPIC 2006 AIVC, the 4th European Conference on Energy Performance & Indoor Climate in Buildings: Technologies & Sustainable Policies for a Radical Decrease of the Energy Consumption in Buildings, Lyon, France, 20-22 November 2006.

Varga, M., Bangens, L., Cavelius, R., Isaksson, C., Laia, C., Leutgöb, K., Lopes, C., Martinez Davison, J., Pagliano, L., Perednis, E., & Read, G. E. F. (2007). *Service Buildings Keep Cool: Promotion of sustainable cooling in the service building sector. Final Report.* Brussels: Intelligent Energy Executive Agency.

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