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Cooling concepts for non-residential buildings: A comparison of cooling concepts in different climate zones

Peter Engelmann[a,*], Doreen Kalz[a], Graziano Salvalai[b]

[a] Fraunhofer-Institut für Solare Energiesysteme, ISE, Heidenhofstr. 2, 79110 Freiburg, Germany
[b] Politecnico di Milano, Department of Architecture, Built Environment and Costruction Engineering, Milano, Italy

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ABSTRACT

This paper investigates, by simulation study, the potential of five different ventilation and cooling strategies with regard to energy efficiency and thermal comfort in different climates. A 5-zones building simulation model is set-up considering a typical office building. The results demonstrate a high potential for night ventilation strategies in cool climates with low ambient air temperatures. In temperate climates, water based low-energy cooling technologies based on radiant cooling make use of the cool ground in summer. Active cooling provides good thermal comfort in warm and hot climates with high and fluctuating cooling loads. The results also point out that the use of different comfort models has a significant influence on the comfort rating.

1. Introduction

Buildings present a very high energy consumption compared to the other sectors. Buildings and Activities in buildings are responsible for a significant share of GHG emissions. In 2010, the building sector accounted for approximately 117 Exajoules (EJ) or 32% of global final energy consumption and 30% of energy related CO_2 emissions and 51% of global electricity consumption. [1].

As a result of the application of intensive energy savings measures and technologies the thermal performance of buildings during the winter period, in terms of reduction of heat loss, improved significantly. On the contrary, the cooling demand is growing because of the increasing of the standard of life, increased internal loads by office appliances and in-creased glazed areas on modern commercial buildings as well as the affordability of the air condition systems [2].

This trend has been amplified by recent warmer summers, in many areas, during which the solar gains play an important role, also in the mid-season months. Apart from these external gains, the internal environment is also subject to heat gains from occupants, equipment and lighting—with the result that modern-day office buildings require cooling practically all year round. Therefore, buildings with a comparatively low heating and cooling demand – the cornerstone of a sustainable energy concept – can be realized in different climates. Those buildings aim to establish a pleasant interior environment without costly building service equipment and without an excessive energy use. A clear definition of low-energy cooling is still missing. In the context of this paper, low-energy cooling refers to cooling technologies which mainly use ambient energy heat sinks such as the cool night air or the ground for cooling (in combination with reversible heat pumps). These concepts base on passive cooling technologies, e.g. free ventilation, solar shading, reduced internal heat gains and high thermal inertia. Mechanical cooling is reduced to a minimum.

High performance buildings have shown that it is possible to go clearly beyond the energy requirements of existing legislation and obtaining good thermal comfort [3–5]. However, there is strong uncertainty in day-to-day practice due to the lack of legislative regulations for mixed-mode buildings, which are neither only naturally ventilated nor fully air-conditioned but use a mix of different low-energy cooling techniques. In this paper the five cooling technologies are evaluated considering both cooling energy reduction and economic aspects. The cooling strategies simulated in this paper could be grouped in three groups: passive cooling, Air-based mechanical cooling and water-based mechanical cooling. Passive cooling and low energy technologies if well

Abbreviations: ACH, air change per hour; BHEX, borehole heat exchanger; COP, coefficient of performance; EIFS, exterior insulation finish system; GHG, green house gas; PMV, predicted mean vote; TABS, thermo active building system; TMY, typical meteorological year; VRF, variable refrigerant flow.

* Corresponding author. Tel.: +49 761 4588 512; fax: +49 761 4588 9000.
E-mail address: Peter.Engelmann@ise.fraunhofer.de (P. Engelmann).

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designed can provide excellent thermal comfort with low energy need. New material, systems and techniques have been developed, applied and now are available on the market [6]. In moderate climates, one promising approach to reduce the energy demand of office buildings for air conditioning without reducing comfort is passive cooling by night ventilation [7]. The cooling peak can be reduced by cooling the construction and interior during the night by using air-ventilation [8] or activated slab. The water based cooling systems are often used in low-energy buildings, considering the possibility to couple with renewable source/sink. For the application of night cooling techniques, natural or mechanical, the most important climatic parameter that affects their efficiency is ambient temperature. Santamouris et al. [9,10] introduced a method to estimate the energy efficiency of night ventilation and its effect in reducing the cooling load of a building. Givoni [11,12], carried-out experiments in buildings with different thermal masses in order to examine how effectively night ventilation can reduce the maximum indoor daytime temperature. Kolokotroni and Aronis [13] examine energy conservation in air-conditioned buildings when night ventilation is applied by natural and mechanical means. Blondeau et al. [14,15] carried out full-scale measurements in order to examine both comfort conditions and energy consumption in order to determine the most suitable ventilation strategy in a specific building, under diurnal or nocturnal ventilation strategies and/or air conditioning. Pfafferott et al. [8] carried-out experiment for both mechanical and free night ventilation in an office building, in order to determine the efficiency of the technique. Salvalai et al. [16] analyzed the performance of the water based cooling systems, concrete core conditioning and suspended ceiling panel, highlighting their energy and comfort performances compared to an air conditioning scenario. Thermally activated building components [17,18], allow to reduce the peak requirements for cooling taking advantage from the thermal mass. Some previous studies [19,20], showed that building with TABS (Thermo Active Building Systems) have higher occupant satisfaction with low energy consumption: about 20% savings, compared to conventional cooling system solutions.

A promising solution to reduce the building energy consumption is to design low-energy buildings with synergy within architectural aspects, low energy cooling systems and renewable energy. Under this premise, the authors analyze different cooling scenarios in terms of energy consumption and thermal comfort analysis in different climates highlighting the influence of different comfort models on the comfort rating.

2. Background and motivation

Cooling demand for comfort purpose in buildings is mainly influenced by climatic conditions and use. Other important factors are building standards, the cooling system installed, and occupant behavior [21].

- Regional climatic conditions: temperature and humidity differences depending on geographical position. The predominating factor is usually the outdoor air temperature.
- Urban climatic conditions: the climate in densely built area can differ from surrounding climate as for example the temperature, wind speed, and humidity.
- Building design: the architectural and structural design features of the building have a strong impact on the indoor climate (building layout, insulation, window orientation, shading, ventilation, daylighting concept, and micro-climate around the building).
- Building use: furthermore internal heat gains from people, lighting, and equipment account for the cooling demand.

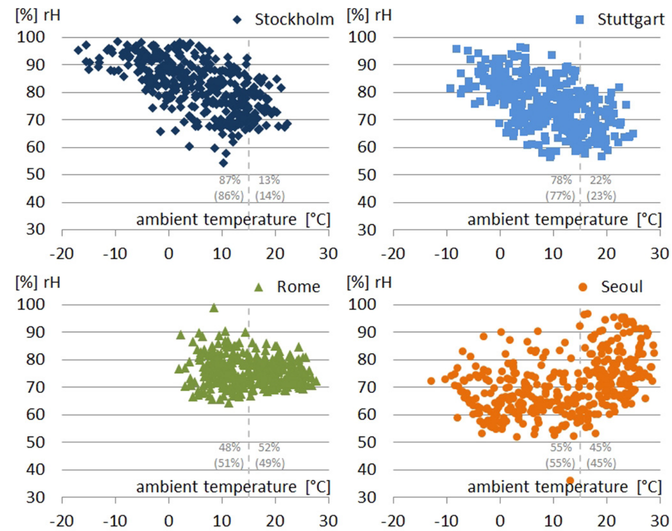

Fig. 1. Scatter plots of temperature and relative humidity as daily mean values of the input data ("typical meteorological year"—TMY2) data. The dashed line represents the threshold between summer and winter. The percentage gives the number of days over or below this limit—based on daily mean values.

- Comfort requirements and use: working hours, vacation period, and the required indoor temperature have a major impact on the cooling demand and consumption.

This analysis focuses on the influence of different ambient conditions and the functionality of cooling concepts; a theoretical, identical building model for five different cooling concepts is set up and tested in different climate conditions. The cooling concepts are analyzed rated with different thermal comfort models, the limits based on the PMV comfort models of EN ISO 7730 [22] and adaptive comfort models as used in EN 15251 [23].

2.1. Climate and boundary conditions

The simulation study is carried out for three different European climate zones and South Korea using a typical meteorological year (TMY) as climate files [24] (Fig. 2). Each climate zone is defined by the mean ambient air temperature in August and is characterized by a meteorological reference station. The daily mean temperatures in summer stay below 16 °C in Stockholm, between 18 and 20 °C in Stuttgart, between 22 and 24 °C in Rome, and exceed 24 °C in Seoul.

Fig. 1 gives a comparison of the parameters "ambient temperature" and "relative humidity" as correlation plot of daily mean values. The threshold for "summer" is marked at 15 °C, according to following Section 2.4. These plots underline the challenges for

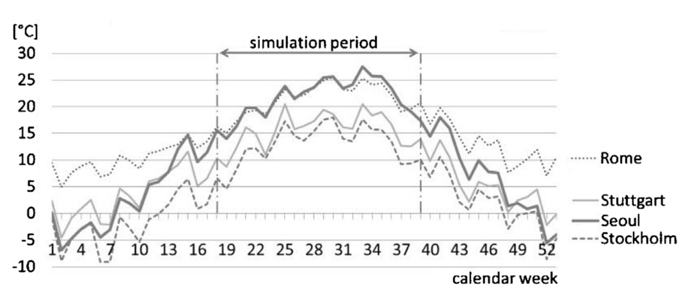

Fig. 2. Line graph of weekly average values for the ambient temperatures in the different sites. Because the study is focused on cooling concepts only the period from May 1st to September 30th is simulated.