Energy and Buildings 82 (2014) 65–72

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A ventilated cooling ceiling with integrated latent heat storage—Monitoring results

Helmut Weinläder[a,*], Werner Körner[a], Birgit Strieder[b]

[a] Bavarian Center for Applied Energy Research (ZAE Bayern), Am Galgenberg 87, 97074 Würzburg, Germany
[b] Dörken GmbH & Co. KG, Wetterstraße 58, 58313 Herdecke, Germany

ARTICLE INFO

Article history:
Received 28 May 2014
Accepted 4 July 2014
Available online 12 July 2014

Keywords:
Phase change material (PCM)
Latent heat storage
Ventilated cooling ceiling
Energy-efficient buildings
Thermal comfort

ABSTRACT

A ventilated cooling ceiling with integrated phase change material (PCM) as latent heat storage was installed in two offices and a conference room. The ceiling was rear ventilated to improve the heat transfer between PCM and room air and its cooling properties were monitored during summer 2009 and 2010. During the day, the ventilation was purely in circulating operation, while cool outside air was used during the night to regenerate the PCM. The ventilated ceiling with PCM reduced the maximum operative room temperature in the office rooms by up to 2 K compared to a reference room without cooling system. For an operative room temperature of 28 °C and a volume flow rate of 300 m^3/h, a cooling power of 30 W/m^2 was measured in the conference room. In the demonstration rooms, it was not possible to insert the fresh air directly onto the PCM as planned. Instead, the outer air entered the rooms via tilted windows or ventilation flaps in the façade, so the cool night air did not reach the suspended ceiling but instead sank to the floor and mixed with the warmer room air. Due to this, the PCM in the suspended ceiling often could not be regenerated completely.

1. Introduction

The energy-efficient cooling of buildings is a task of increasing importance. Due to light-weight construction and a tendency towards façades with more and more transparent elements, overheating is becoming a major problem. Particularly in office and public buildings, cooling systems have become a common part of the energy concept. Unfortunately, many conventional cooling systems require large amounts of primary energy, thus increasing the greenhouse gas emissions and boosting the operating costs of buildings. Phase change materials (PCM) offer a promising alternative and are one of the main focus topics in research with a large number of publications every year in the field of building applications. While many studies in East Asian countries investigate the application of PCM for room heating, e.g. [1–3], or a combination of heating and cooling [4,5], the main application for PCM in Middle and South European countries is room cooling [6–8]. Passive systems are energy-efficient and usually require low maintenance, but the regeneration of the PCM through free cooling often is a problem [9], especially if the PCM is incorporated into the room walls or ceiling due to the limited heat transfer between air and room surfaces. Even with a ventilation system to increase the night time air exchange rate, the regeneration process can be problematic, as described for example in [10], where the main reason for the inefficient regeneration was the temperature rise of the cool night air on its long way to the PCM along the ducts of the central ventilation system. Therefore we investigated a decentralized ventilation system with short distances between air inlet and PCM. In a first step, the system was installed and measured in a laboratory test room at ZAE Bayern [11]. The results were used to optimize the system design of the suspended and rear-ventilated ceiling for the monitoring test rooms:

- The PCM containers were placed flat on top of the bearing for the plaster boards,
- the volume flow rate of the air through the suspended ceiling was designed to be as high as possible, and
- the amount of PCM per floor area was in the range of 5 kg/m^2.

2. Monitoring results

2.1. Description of test rooms

A conference room located in Würzburg University and two offices located inKarlsruhe were available as test rooms. The

* Corresponding author. Tel.: +49 931 70564 348; fax: +49 931 70564 600.
E-mail address: Helmut.Weinlaeder@zae-bayern.de (H. Weinläder).

http://dx.doi.org/10.1016/j.enbuild.2014.07.013
0378-7788/

Nomenclature

A_{PCM}	ceiling area covered with PCM (m^2) (in contrast to the whole ceiling area)
c_L	specific heat capacity of air (Wh m^{-3} K^{-1})
λ_{pb}	thermal conductivity of plaster board (W m^{-1} K^{-1})
n	air exchange rate (h^{-1})
Q_{ca}	cooling power of the air in the ventilated ceiling (W)
Q_{cei}	cooling power of the PCM through the plaster board ceiling (W)
Q_{reg}	cooling power of the air for the regeneration of the PCM (W)
Q_t	total cooling power of the ventilated cooling ceiling (W)
q	specific cooling power (Wm^{-2})
T_i	inlet air temperature (K)
T_o	outlet air temperature (K)
t_{pb}	thickness of plaster board (m)
$T_{pb,u}$	surface temperature on upper side of plaster board (K)
$T_{pb,l}$	surface temperature on lower side of plaster board (K)
$\dot{V}$	air volume flow rate (m^3h^{-1})

conference room has a floor area of 45 m^2 and faces east with a window area of about 35%. It was used irregularly by 5–15 persons. Metal containers from the company Matino filled with the PCM DELTA®-COOL 24 by the company Dörken were used (Fig. 1). The metal containers were laid on top of the bearing for the plaster boards (Fig. 2). About 56% of the ceiling area could be covered with PCM. The total amount of PCM was 180 kg, which resulted in a mass of PCM per floor area of about 4 kg/m^2.

Fig. 3 shows the operation modes of the ventilated cooling ceiling: During daytime, the ventilation is in purely circulating operation guiding the warm room air onto the PCM; during night time, cool outside air is used to regenerate the PCM.

The laboratory measurements in [11] indicated, that the volume flow rate through the ceiling should be as high as possible to achieve a significant cooling power of the air flow. Therefore, the ventilation system (Fig. 4) in the conference room allows a volume flow rate of 300 m^3/h (air exchange rate n = 2.5/h) during circulating operation, which was the trade off between high air flow rate and low noise. To achieve a good regeneration of the PCM, the cool ambient air ideally should be directly connected to the suspended ceiling. Unfortunately, this was not possible in the conference room because the façade must not be penetrated. Instead, the windows could be tilted by motor-controlled actuators and the incoming air had to reach the suspended ceiling by air inlets in the plaster boards near the windows (Fig. 5). The exhaust air then was inserted into the exhaust air duct of the university where it was blown to the exterior. During regeneration mode at night no people are in the conference room, so the volume flow rate was turned to maximum 600 m^3/h (n = 5/h).

The two offices are oriented westward with a window area of about 50% of the outer façade surface. An additional similar office room without a PCM system was used for comparison measurements. Each of the offices was occupied by two people, and contained typical office equipment like computers and monitors. The PCM in the office rooms was encapsulated in newly developed plastic boards from the company Dörken (Fig. 6). With these so called DELTA®-COOL boards, a total amount of 190 kg of the PCM DELTA®-COOL 24 was incorporated into each room (Fig. 7). With a floor area of 29 m^2 per room, this equals a mass of PCM per floor area of about 6.5 kg/m^2.

The volume flow rate in the offices was 150 m^3/h (n = 2/h) in circulating operation. In the offices too it was not possible to insert the cool ambient air for the regeneration of the PCM directly into the suspended ceiling. Instead, ventilation flaps in the façade were installed that opened during the night (Fig. 8). The incoming air then had to go through a gap in the ceiling to enter the suspended ceiling and to reach the PCM. The exhaust air was blown to the exterior through an air duct located in the reference room. The volume flow rate during the nightly regeneration was 300 m^3/h (n = 4/h). While one of the office rooms was equipped only with the ventilated ceiling with PCM, the other test room had an additional sun protection system with PCM. A description of the sun protection system and its performance can be found in [12].

To eliminate the influence of the room users, all measurements in the rooms were performed on weekends or when no users were present. The internal gains were simulated by electrical heaters with a power of 500 W in the offices, and 1000 W in the conference room to account for its higher occupancy. The operative room temperature was measured with a self-built globe thermometer

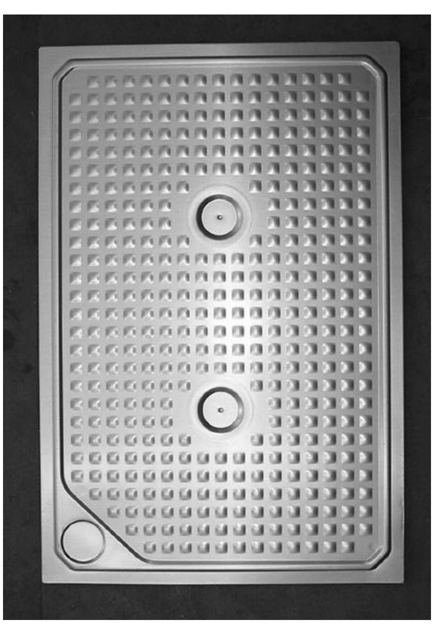

Fig. 1. Metal board from the company Matino filled with the salt hydrate DELTA®-COOL 24 by the company Dörken.

Fig. 2. Installation of the PCM boards in the conference room in Würzburg.