available at www.sciencedirect.com

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

Experimental investigation of energy saving in buildings with PCM cold storage

U. Stritih*, V. Butala

Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, 1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 26 January 2010
Received in revised form
16 July 2010
Accepted 17 July 2010
Available online 24 July 2010

Keywords:
Air conditioning
Cooling
Building
Thermal storage-material
Phase change
Free cooling
Experiment

ABSTRACT

This article presents an experimental analysis of cooling buildings using night-time cold accumulation in a phase change material (PCM), otherwise known as the "free-cooling principle". Studies of the ceiling and floor free-cooling principle, as well as passive cooling, are presented. The free-cooling principle is explained and some of the types of PCMs suitable for summer cooling are listed. An experiment was conducted using paraffin with a melting point of 22 °C as the PCM to store cold during the night-time and to cool hot air during the daytime in summer. Air temperatures, heat fluxes and heat as a function of time are presented for different air velocities and inlet temperatures.

Etude expérimentale sur les économies d'énergie engendrées par l'accumulation thermique grâce aux matériaux á changement de phase

Mots clés : Conditionnement d'air ; Refroidissement ; Immeuble ; Accumulation thermique-matériau ; Changement de phase ; Froid naturel ; Expérimentation

1. Introduction

European Directive 2002/91/EC (2002) points out that buildings play a crucial role in long-term energy consumption and that new buildings should therefore meet minimum energy performance requirements tailored to the local climate. As the application of alternative energy supply systems has not been fully explored, the technical, environmental, and economic feasibility of such alternative energy supply systems should be considered. The rise in the number of air-conditioning systems creates considerable problems at peak energy load times. Therefore, priorities should be given to strategies that

* *Corresponding author*. Tel.: +386 1 4771 312; fax: +386 1 2518 567.
E-mail address: uros.stritih@fs.uni-lj.si (U. Stritih).

0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2010.07.017

Nomenclature

Quantities

A	area for airflow (m^2)
c_p	specific heat capacity at constant pressure ($J\ kg^{-1}\ K^{-1}$)
h	enthalpy ($kJ\ kg^{-1}$)
L	latent heat ($J\ kg^{-1}$)
l	characteristic value (m)
m	mass (kg)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
Q	heat (J)
T	temperature (K)
t	time (s)
V	volume (m^3)
v	velocity ($m\ s^{-1}$)
Φ	heat flux (W)
τ	dimensionless time (/)
λ	thermal conductivity ($W\ m^{-1}K^{-1}$)
ρ	density ($kg\ m^{-3}$)
ΔT	temperature difference (K)
Δt	time interval (s)

Subscripts

0	initial
f	final
i	inlet
j	certain time
l	liquid
m	melted
max	maximum
n	number of time intervals
o	outlet
PCM	phase change material
s	solid

enhance the thermal performance of buildings during the summer period. To this end, there should be further development of alternative cooling techniques.

Thermal energy storage in general and PCMs in particular have been a central topic in research for the last 20 years. However, although there is a large amount of information on this topic, it is scattered throughout the literature and quite difficult to find. Reviews of the literature have been carried out from three points of view: materials, heat transfer, and applications. Because of the high thermal mass of PCM walls, they are capable of minimizing the effect of large fluctuations in ambient temperature on the inside temperature of a building (Bony and Citherlet, 2007; Farid et al., 2004; Khudhair and Farid, 2004; Zalba et al., 2003). They can therefore be very effective in shifting the heating and cooling load to off peak electricity periods.

Studies of the thermal behavior of wallboards containing PCM have been carried out in order to build a light building envelope. Three types of wallboard containing a PCM were studied experimentally. It was found out that the envelope had a very high thermal capacity and no deterioration was noted after more than 400 cycles (Ahmad et al., 2006). A numerical study of wallboard with latent heat storage examined the thermal dynamics of PCM wallboard that was subjected to diurnal variations in room temperature in order to select the optimal PCM material (Neeper, 2000). A simplified analytical model for two-phase solidification in finned PCM storage was made. It is based on a quasi-linear, transient, thin-fin equation, which predicts the solid–liquid interface location and temperature distribution of the fin in a solidification process with a constant end-wall temperature in a finite PCM store (Lamberg, 2004). PCM integrated into a building wall acts like a heat reservoir, thereby reducing room temperature. This effect leads to reduced cooling loads or, in the absence of an air conditioner, to a significant increase in comfort (Carbonari et al., 2006; Fang and Zhang, 2006; Jaworski and Wawreszuk, 2003; Schossig et al., 2003, 2005; Stritih, 2004). The results of using a statistical approach is to evaluate the thermal behavior of the PCM containing walls are twofold: firstly, it demonstrates the existence of statistically significant linear dependences among the variables used, and, secondly, highlights the improvements in comfort conditions due to the insertion of PCM inside dry assembled walls (De Grassi et al., 2006).

PCM has also been developed to store “coolness” for air-conditioning applications. The “cold” is collected and stored in the PCM during the night and used to cool the interior of the building during the hottest hours of the day. This concept is known as free cooling. A mathematical model of a PCM air heat exchanger has been made. In order to cool a given space with cold night air, PCM is stored in an air heat exchanger. During the night, the PCM crystallizes and energy is released. During the daytime, air is circulated through the unit, heat is absorbed and the indoor air is cooled (Hed and Bellander, 2006). The conclusion of an experimental study of heat transfer in a rectangular PCM thermal storage was: heat storage (melting) is not a problem during thermal storage applications and that the extraction of heat (solidification) can be effectively enhanced using fins (Stritih, 2004).

Floor heating systems with PCM have also been studied. The thermal characteristics of manganese (II) nitrate hexahydrate as a PCM in a cooling system have been evaluated. It was found out that the thermal properties of manganese (II) nitrate hexahydrate gave a strong potential as a PCM for thermal energy storage (TES) in cooling systems (Nagano et al., 2003). Thermal characteristics of a direct heat exchange system between PCM and air was also studied; it was found out that the amount of exchanged heat can be quite large during the phase change (Nagano et al., 2004). A ventilation system utilizing thermal energy storage via granules containing PCM in order to reduce ventilation load during summer was investigated in eight cities in Japan using computer simulation (Takeda et al., 2004). A floor supply air-conditioning system using PCM to augment the building’s mass thermal storage was studied. Heat response tests revealed that the temperature stabilization effect during the time that the phase change was occurring increased the time constant of the room temperature by a factor of 1.5–2.1 when a PCM packed bed was installed. Results from measurements indicate that 89% of the daily cooling load could be stored each