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On the placement of a phase change material thermal shield within the cavity of buildings walls for heat transfer rate reduction

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ABSTRACT

PCMs (Phase change materials) are used to enhance the thermal storage capacity of building walls, decrease indoor air temperature fluctuations, and shift peak heat transfer rates to off-peak times. PCM location within building walls is recognized to be critical for the optimum performance of the system. One possible integration of the PCM into a wall could be via a PCM-layer or "shield," herein referred to as "PCMTS" (PCM Thermal Shield). A prototype PCMTS was developed and its thermal performance was evaluated in three different locations within the cavity of a typical North American residential wall system using a dynamic wall simulator in this paper. The experimental results showed that, compared to a wall without a PCMTS, the peak heat fluxes were reduced by as much as 11% when the thermal shield was placed in the inward-most location next to the internal face of the gypsum wallboard within the wall cavity. The PCM thermal shield produced only small effects on the peak heat fluxes when it was placed half way between the enclosing surfaces of the internal cavity of the wall and almost no effect when it was placed next to the internal face of the outermost layer of the wall.

1. Introduction

In many countries, the energy consumption in buildings is significant. The estimated consumption of energy in the United States in 2010 was 28.7 × 10^9 MWh, 40 percent of which was used in buildings. Of the total energy consumed in U.S. buildings, 20 percent was used for space heating and 13 percent was used for space cooling [1]. In 2010 China had an energy consumption of 27.4 × 10^9 MWh, 30 percent of which was consumed by buildings [2]. Energy use in China is expected to increase by 53% by 2035 [3]. Furthermore, during the summertime's peak hours, air conditioning equipment demands a major part of the total electrical energy, which in many areas, both in the United States and in China, the electrical utility companies would not fully support, which results in rolling brownouts and blackouts [4,5]. Consequently, new technologies that can alleviate this situation have been proposed, of which PCMs (Phase change materials) is one that is beginning to be recognized as an effective one that can contribute to the reduction of the peak heat transfer rates and eventually reduce energy consumption [6–9].

The thermophysical properties of the materials used in walls and ceilings can significantly influence the heat transfer rates, and thus, the space cooling and space heating loads in buildings. Furthermore, the thermal storage capacity of modern lightweight residential walls used in North American construction and ceilings is low, and as a result, wall, ceiling, and indoor air temperatures undergo large fluctuations. These fluctuations in temperature contribute to occupants' discomfort. In addition, these fluctuations are responsible for space cooling and heating equipment into short on–off cycles. Short on–off cycles result in diminished interior moisture removal during the summer and reduced equipment operational lifetime. Because PCMs have relatively large latent heats of fusion, incorporating them into building walls and ceilings can potentially increase the thermal mass of these enclosure components, which could not only decrease heat transfer rates during peak hours, but also reduce the relatively large interior temperature fluctuations and enhance human comfort [6,10–13]. Jiang et al. [14] analyzed the intrinsic performance of the internal envelope controlling indoor air temperature and optimized the

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specific heat. They found that the optimal specific heat of internal envelope approached to the equivalent specific heat form of phase change material. Mandilaras et al. [15] built a two-story typical family house outfitted with PCM walls. The experimental results showed that the thermal mass of the wall was enhanced during late spring, early summer and autumn. The decrement factor was reduced by 30–40% and the time lag was increased by approximately 100 min. Sá et al. [16] developed a new composite construction material that embedded micro-encapsulated PCM in plastering mortar. It was found that the peak temperature of the indoor air was reduced by 2.6 °C when the PCM mortar was used. Voelker et al. [17] studied the effect of PCMs on room temperature reduction. Their results showed that the temperature reduction was up to 4 °C during peak times compared with a room without PCM. Kuznik et al. [18] showed that a wall outfitted with PCM assisted in maintaining the room air temperature within the comfort zone by lowering the maximum air temperature of the room by a maximum value of 4.2 °C.

However, in the previous research, the PCM layer was usually placed close to the indoor environment. For example, a wallboard immersed with PCMs was placed on the interior surface of the wall [15–17,19,20]. Other locations for a PCM layer, such as close to the exterior surface of the wall [21], or next to the internal face of gypsum board [18], or within the insulation cavity [22] have appeared in the literature. Previous research by the authors of this article [23], related to the dependence of wall thermal performance on PCM location, found that because PCMs have their own melting temperature ranges and given that temperature profiles across walls differ, PCMs experience different thermal cycles when they are placed in different locations within walls. That is, PCM location within walls affects phase change process and it is critical for the optimum thermal performance of walls outfitted with PCMs. As a result, the placement of PCMs within building walls should be evaluated. In this paper, a new PCM thermal shield was developed and its thermal performance was studied as a function of shield location within the cavity of a typical North American residential wall.

2. Experimental set-up

2.1. PCM thermal shield

The PCM used in this research was n-octadecane, which is an organic paraffin. This PCM was chosen because it was non-toxic, non-corrosive, had a high thermal storage capacity, and melted at the appropriate temperature range for the proposed application. The thermophysical properties of the PCM are shown in Table 1.

Several small thermal resistance plastic pouches (10.15 cm × 5.07 cm) were used to hold the PCM. The total amount of PCM was equivalent to 10% of the weight of the wallboard. This is referred in the literature to as 10% PCM concentration [22]. Because the PCM would expand while melting, only two thirds of each plastic pouch was filled. After the pouches were prepared, they were attached in a cardboard (38 cm × 107 cm). The schematic of the PCMTS (PCM thermal shield) is shown in Fig. 1.

Table 1
Properties of n-octadecane [26].

Properties	Description
Appearance (solid)	White crystal
Density (solid), kg/m^3	870
Density (liquid), kg/m^3	750
Specific heat capacity (solid), kJ/(kg K)	1.8
Specific heat capacity (liquid), kJ/(kg K)	2.4
Melting point, °C	28
Freezing point, °C	26
Flash point, °C	146
Heat conductivity, W/(m K)	0.2
Latent heat of fusion, kJ/kg	179

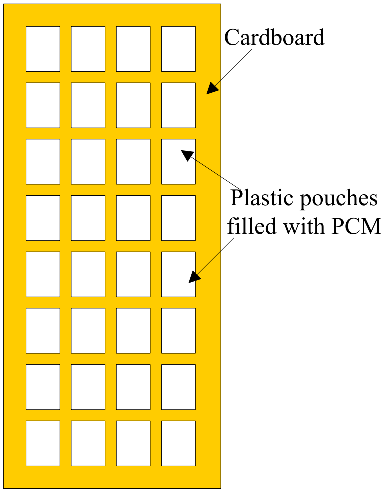

Fig. 1. PCM thermal shield.

2.2. Dynamic wall simulator

The thermal performance of walls outfitted with PCMTS was tested using a dynamic wall simulator (Fig. 2). The simulator was a cubic box which held six 1.19 m × 1.19 m wall panels. Two wall panels were used to test the performances of walls with and without the PCMTS. The wall without the PCMTS was referred to as the control wall, which consisted of a gypsum wallboard (12.7 mm), a cardboard (to cancel the effects of the cardboard used in the

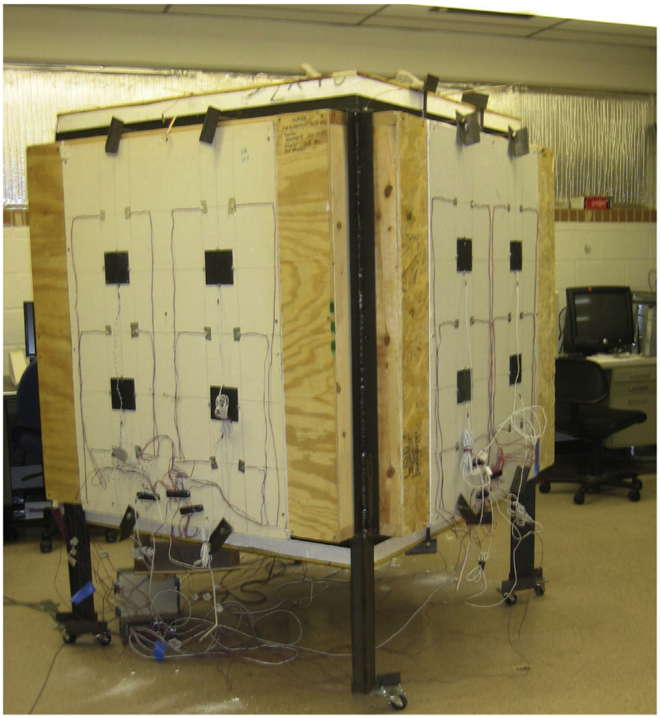

Fig. 2. Dynamic wall simulator.