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Energy saving potential of a novel phase change material wallboard in typical climate regions of China

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ABSTRACT

A novel wallboard with double layers shape-stabilized phase change materials (SSPCMs) for year round energy management was proposed. Its energy saving potential in five typical climate regions of China was studied. One office room integrated with double layers SSPCMs wallboard was used for simulation platform. The other normal office room with the same envelope and just without double layers SSPCMs wallboard was used as reference room. Studies were conducted to investigate the energy saving potential of double layers SSPCMs wallboard in five cities representing five typical climate regions of China, including severe cold region, cold region, hot summer and cold winter region, hot summer and warm winter region, mild region. The optimal melting temperature and corresponding thickness of SSPCMs wallboard in five representative cities were given when the energy saving potential reached maximal value. It concluded that the optimal melting temperature of internal SSPCM layer was effected by indoor air temperature and the optimal melting temperature of external SSPCM layer was effected by outdoor air temperature. The characteristic of optimal values in the five representative cities were given for reference in this paper.

1. Introduction

The use of phase change materials (PCMs) integrated into building envelopes had attracted more and more attentions. The available PCMs suited for building applications had large thermal storage capacity in lightweight construction. PCMs used in buildings can enhance the indoor thermal environment and reduce the energy consumption for space heating and cooling. The shape-stabilized phase change material (SSPCM) had attracted interests of the researchers [1–4]. It reduced the liquid PCM leakage danger and can be used for thermal storage in buildings without encapsulation.

Zhou et al. [5–8] studied on the indoor thermal characteristic and energy performance of SSPCM wall and floor in summer and winter. The numerical and experimental studies were conducted to analyze the optimal utilization of SSPCM in building envelopes. They showed that the SSPCM could improve the indoor thermal comfort level and save building operation energy consumption compared with the case without SSPCM.

Ahmad et al. [9] studied on the thermal performance of a light wallboard integrated with PCMs in varied climate. Then a comparison was made between the novel structure and a test-cell without PCMs. A vacuum insulation panel was associated to the PCM panel to improve the wallboard efficiency. This study showed that the indoor temperature amplitude was reduced by 20 °C approximately in the test-cell. The PCM structure showed significant heat storage and release capacity with varied external temperature swings.

Kong et al. [10] proposed two new PCM systems, PCMOW (capric acid contained in the panels installed on the outside surface of building) and PCMIW (capric acid and 1-dodecanol contained in the panels installed on the inside surface of building). A one-dimensional transient mathematical model and its experimental validation had been investigated theoretically in this paper. PCMIW performed better than PCMOW with nature ventilation, but the PCMIW application will need the indoor envelope retrofit in the existing buildings.

Meng et al. [11] investigated thermal characteristics of a composite PCM structure by simulation and experiment. Two different kinds of PCM were placed on the wall in different orientations. Results showed that this new type of PCM room can decrease the indoor air temperature fluctuation by 4.3 °C in summer and 14.2 °C in winter. Different arrangements of the two kinds of PCM in the room can cause an indoor air temperature difference to be 6.9 °C in summer and 2.7 °C in winter. Moreover, it was found that the

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Nomenclature

c	Specific heat (kJ/(kg K))
c	Capacitance (kJ/K)
C	Capacitance (kJ/K)
C_p	Specific heat (kJ/(kg K))
D	Thickness of SSPCM panel (m)
E	Electricity consumption (kWh)
H	Latent heat (kJ/kg)
P	Peak load reduction
R	Resistance (K k/W)

Greek symbols

λ	Conductivity (W/(m K))
ρ	Density (kg/m^3)
τ	Time (s or h)

Subscripts

ave	Average
C	Cooling
diff	Difference
H	Heating
m	Melting point of SSPCM
out	Outdoor air
db	Outdoor design dry-bulb temperature for summer air conditioning
wb	Outdoor design wet-bulb temperature for summer air conditioning
SSPCM	Shape-stabilized phase change material
sa	Saving

selection of melting temperature and thickness influenced melting speed and rate.

The single layer SSPCM element was studied by most researchers. It was used for improving indoor thermal comfort and reducing cooling/heating load. But it couldn't achieve energy management round a year since it was only active in summer or in winter. There were a few studies concentrated on double layers SSPCMs wallboard used in buildings.

Diaconua et al. [12] proposed a PCM wall with middle layer consisting of insulation panel (100 mm) and external/internal layer consisting of PCM wallboard (50 mm). Its potential for cooling/heating energy savings in a year-round was evaluated in continental temperature climate. It was found that the new wall system contributed to annual energy savings (1% cooling energy saved in summer and 12.8% heating energy saved in winter) and reduced the peak values (24.3% for cooling and 35.4% for heating) of the cooling/heating loads. But the author pointed out that the characteristics of the wall system were not optimized. Insulation panel was chosen as the main structure of the wall which was not the common used envelope in actual buildings, therefore the actual value of the energy savings was of little relevance.

Jin et al. [13] put forward a double-layer PCM floor. The two layers of PCM had different melting temperature. The system was used to store energy in the off-peak period and release them in the peak period during heating or cooling. The results showed that the optimal melting temperatures of PCMs existed. The indoor thermal comfort was improved both in winter and summer after heating or cooling system had been turned off for a long time. Compared to the floor without PCM, the energy released by the floor with PCM in peak period was increased by 41.1% and 37.9% during heating and cooling period, respectively.

Pasupathy et al. [14] studied the thermal performance of an inorganic eutectic PCM based on thermal storage system for thermal management in a residential building. The system had been analyzed numerically and experimentally. A double layers PCM concept was proposed and studied to achieve year round thermal management passively. The double layers PCMs clung to each other and were regarded as a whole panel. It was found that the PCM could reduce the internal air temperature swing during winter seasons, but it was not suitable in summer as the PCM remained in the liquid state all times during these months and hence the system cannot exploit the latent heat effect. Therefore, melting temperature of PCM was a very important factor on building cooling and heating load.

This study aimed at determining the optimum melting temperature of the external/internal SSPCM reached the minimal amount of cooling load/heat gain in summer and maximum amount heating load/heat loss in winter. This temperature had also been studied by different researchers [15–20].

Fiorito [15] selected five cities of different climate zones in Australia and modeled the effect of PCMs (*n*-paraffin and wax) integrated in collector-storage walls. The simulation results showed that PCM improved the thermal inertia of lightweight constructions, and its position and melting temperature were needed to be optimized according to different climate conditions.

Peippo et al. [16] concluded that the phase change temperature should be 1–3 °C higher than indoor temperature to maximize the heat absorbed during diurnal period. Neeper [17] analyzed a PCM wallboard with diurnal variations in indoor temperature but without direct solar radiation. It pointed out that the optimum transition temperature of the PCM should be close to indoor temperature to minimize the thermal load of the building. Heim and Clarke [18] selected a phase change temperature of 22 °C, which was 2 °C higher than the indoor comfort temperature.

Izquierdo-Barrientors et al. [19] developed a one-dimensional transient heat transfer model by a finite difference method. Different external building wall configurations were analyzed for a typical building wall in varied location of the PCM layer, the orientation of the wall, the ambient conditions and the phase transition temperature of the PCM. There was not a definite optimum temperature to minimize the cooling/heating load through the building wall. Under the conditions used in this work, the optimal melting temperature was between 5 °C and 35 °C, depending on seasons, wall orientations and locations of the PCM layer.

Zhang et al. [20] reviewed that the optimal value of the melting temperature depended on the average room temperature, which varied from building to building and from season to season. This provided a general conclusion on optimal melting temperature of PCM when integrated into building envelopes.

This paper presented a numerical simulation of transient heat transfer through an office building exterior wall with double-layer SSPCMs wallboard in five representative cities in typical climate regions of China. This paper investigated reliable melting temperatures of external/internal SSPCM layer in office building. The correlation between optimal melting temperature of external layer and outdoor air temperature in office building in China typical climate zones was studied in this paper. And the correlation between optimal melting temperature of internal layer and indoor air temperature in office building in China typical climate zones was also studied. In each case, the thicknesses of double layers SSPCMs wallboard had been varied to find the optimal melting temperature that minimize the energy demand of the building due to heat transmission though the walls. This paper aimed at evaluating the energy saving potential of double layers SSPCMs wallboard for office buildings in different climate regions. Optimal values, including melting temperature and thickness, in ten cases also could be obtained based on the simulation results.

In the following sections, the test platform and weather profiles used in the simulations were introduced. Next, the heat transfer