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Preparation and Thermal Performance of Diatomite-Based Composite Phase Change Materials Wallboard

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ABSTRACT
Two kinds of diatomite-based composite phase change materials (the phase change temperature was 35℃ and 42℃, respectively) were prepared by incorporating organic alcohol phase change materials into diatomite to form shape-stabilized composite PCMs. Then, diatomite-based phase change wallboards were fabricated, and the wallboards were attached to the exterior surface of the wall from a test small room to study the thermal performance. In this study, we investigated the effects on the wallboards location, the type of materials and the phase transition temperature on the thermal performance of the wallboards. It was found that comparing with the traditional polystyrene plastic insulation wallboard, the external surface temperature of the PCMs wallboards can be obviously lower than that of the traditional insulation wallboards due to thermal storage ability. But the thermal resistance of the PCMs wallboards was too small to reduce the indoor cooling load in summer comparing with the conventional polystyrene insulation wallboard. The suitable phase transition temperature for the PCMs wallboard was dependent on the orientation of the wall. At the same time, the optimal phase transition temperature is not just dependent on the outdoor meteorological conditions, but also relevant to the applied scenarios.

KEYWORDS
Phase change materials; PCMs wallboard; Diatomite; Insulation wallboard

INTRODUCTION

In China, the building energy consumption has up to 40% of the annual energy production during the last several years, which more attention has been taken to use the renewable-energy resources [1]. One of the effective ways to minimizing the building consumption and keep the thermal comfort of the living room is to use the latent heat storage system such as PCMs, which has attracted more and more attention by abounding researchers. Phase change materials (PCMs) can be used storage and release large amount of energy during melting and solidification at a constant temperature.

It is well known that the thermal insulation performance of the envelope is one of the important factors that affect the energy consumption of the building [1]. Thus, applying the PCMs to building envelope is a potential way for improving the indoor thermal comfort and energy saving. At the early stage, the combination of PCMs with building envelope, includes two principal types [2]: directly incorporating PCMs with concrete or gypsum, and macro-encapsulation. However, the leakage and poor thermal conductivity of PCMs restrict their further application. Recently, there were two main technical routes developed to address above problems [3]: 1) Encapsulating PCMs into porous materials to form shape-stabilized PCMs; 2) Another potential way is the encapsulation of PCMs into polymeric or inorganic materials. Comparing the second route, encapsulating PCMs into porous materials is more efficiency and low-cost. Diatomite, also called diatomaceous earth, it was lightweight, high porosity, high absorptivity, high purity, multi-shape, rigidity, and inertness. Both the chemical composition and the physical structure of diatomite make it suitable for many scientific and industrial purposes. Besides, diatomite has excellent compatibility with concrete as the inorganic supporting materials [4].

In this study, diatomite was used as the supporting material. Commercial organic PCMs named MG35(tetradecanol) and MG42 (hexadecanol) was utilized as the working substance to prepare diatomite-based composite PCMs by physical adsorption method. Then the composite PCMs was directly mixed with concrete to fabricate phase change wallboards for test. In the earlier study, phase change wallboards were mainly placed on the interior surface of the wall to regulate the indoor temperature. However, there was few research was reported the application of PCMs wallboards placed on the exterior surface. Comparing with placing the PCMs wallboard on the interior surface, the fluctuates of exterior surface temperature was more obviously, which was helpful for the PCMs to undergo the whole phase transition process [5]. There was a large temperature difference during day and night, which was in favor of the PCMs store and release energy. In our study, the wallboards were attached to the exterior surface of the west wall from a real size room. Polystyrene insulation board and expanded perlite board were tested as a comparison group. The performances of heat insulation and temperature change of the wallboards were investigated.

MATERIALS & METHODS

Materials

90% particle size of expanded perlite used in this study was between 0.28-1.25mm. Two commercial PCMs named MG35(tetradecanol) and MG42(hexadecanol) were used in our study. The nominally latent heat of MG35 and MG42 is 178 J/g according to product information. The two materials were tested by the Q100-DSC instrument from TA company. Figure.1(a) displayed the DSC curves, which indicated that the phase transition temperature range of MG35 and MG42 is 33-36℃ and 42-45℃, respectively. The main physical parameters of the four functional materials were shown in Table 1.

Table 1 Properties of raw materials

Type	Density (kg/m^3)	Thermal conductivity (W/m·k)	Phase change Temperature (℃)
Polystyrene	30	0.042	-
Expanded perlite	55	0.0235	-
MG35 (Tetradecanol)	835	0.147	35
MG42 (Hexadecanol)	840	0.148	42

Preparation of diatomite-based composite PCMs

(1) A simple physical blending method was adopted to adsorb these two kinds of PCMs into diatomite to form composite PCMs, respectively. Briefly, the diatomite was dried at 95℃ for 24h. Then the PCMs particles were heated and blended with the diatomite to form composite PCMs. The mass content of PCMs in composite PCMs was 50%, due to the over high content of the PCMs is prone to serious agglomeration and leakage [6].

Preparation for wallboards

The cement and sand were mixed in a ratio of 5:3 with the addition of composite PCMs. Then, water was added (water/cement ratio is 1:2). Subsequently, wallboard samples were made by filling the mixture into homemade molds. The dimensions of boards and the percentages of composite PCMs were shown in Table 2. After 24h, the pre-prepared wallboards were cured in a standard curing room for 28 days. The prepared wallboards are shown in Figure 1 (d).

Table 2. Parameters of four types of wallboard

Type	Expanded perlite wallboard	MG35 diatomite-based wallboard	MG42 diatomite-based wallboard	Polystyrene wallboard (EPS)
Size	300mm×300mm×30mm			
Composite PCM and mass percentage	Perlite 40%	MG35 diatomite composite 60%	MG42 diatomite composite 60%	Polystyrene 100%
Density (kg/m^3)	741	1344	1257	30
Thermal conductivity	0.26	-	-	0.042

Fig.1 (a) DSC curves of PCMs; picture of (b) Pure PCMs; (c) Composite PCMs; (d) prepared wallboards

Test methods

The as-prepared wallboards were respectively attached to the exterior surface of the east and west wall (the wall was built by regular vitrified bricks) of two adjacent test room located at Tongji University. A big frame (1200 × 1200mm) was divided into four small frames (600×600mm), and each small frame was attached with four same wallboards. The distribution of the four small frames with different wallboards was shown in Fig. 2(a). Finally, all the wallboards were coated with a layer of 5mm thick cement mortar. Thermocouples were arranged on the interior and exterior surfaces of each wallboard, and the data was recorded by a data acquisition instrument. The test was last six days from August 30 to September 5, 2016.

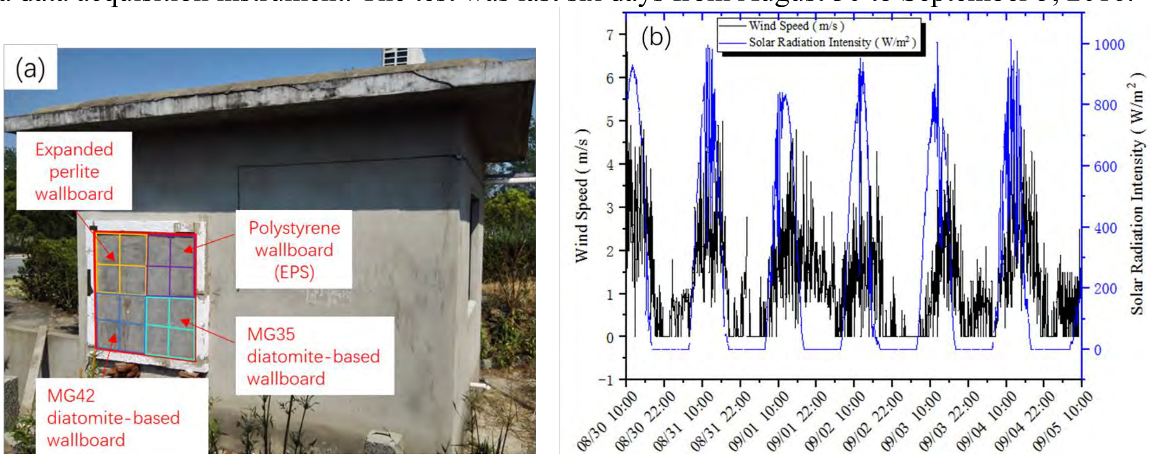

Fig.2 (a)Test room; (b) Outdoor weather data

RESULTS & DISCUSSIONS

Outdoor thermal environment

The as-prepared boards were all exposed to direct solar radiation at 14:30 until the sunlight was completely blocked by the tall buildings at 18:00. The outdoor weather data were plotted in Fig.2(b). As Fig.2(b) shown, all the test days were sunny and the total solar radiation intensity up to 1000W/m^2 at midday. The outdoor wind speed was between 1.5-2.5m/s.

Results of the west wallboard

The temperature history curves of the exterior surface of the four different kinds of wallboards on the west wall were displayed in Fig.3(a). During the daytime, the maximum temperatures of the exterior surface of the four wallboards were in order of the insulation board > perlite board > MG35>MG42. However, during the night, the minimum temperatures of the exterior surface of the four wallboards were in the order of MG35 > MG42 > perlite board > insulation board. The maximum and minimum temperatures of four kinds of wallboard occurred at around 4:00 pm and 5:30 am, respectively. Comparing with the common wallboard, there was no significant time delay was found from the exterior surface temperature of the PCMs wallboard.

Take the data of September 3 as an example for analysis, the results were displayed in Table 3. It is obviously found that the exterior surface temperature of the conventional polystyrene board could reach 54℃, which was nearly 16℃ higher than the outdoor temperature. This phenomenon possible due to the polystyrene board has high thermal resistance and small heat storage ability. The high temperature of exterior wall face will make people thermal discomfort when people move around the exterior wall because of the high radiation from the exterior wall. For the other three kinds of wallboards, the maximum temperatures of the exterior surface were lower 4-9℃ then that of polystyrene board. The reason is that the other three kinds of wallboards have excellent thermal storage ability and high conductivity, which can store the heat from the outdoor radiation to reduce the temperature of the surface during the daytime. During the night, the exterior surface temperature of the insulation board was basically consistent with the outdoor air temperature. However, the exterior surface temperatures of other three kinds of wallboard were slightly higher than that of the polystyrene board. The reason is that the heat storage in the wallboard begins to release to the outdoor environment slowly.

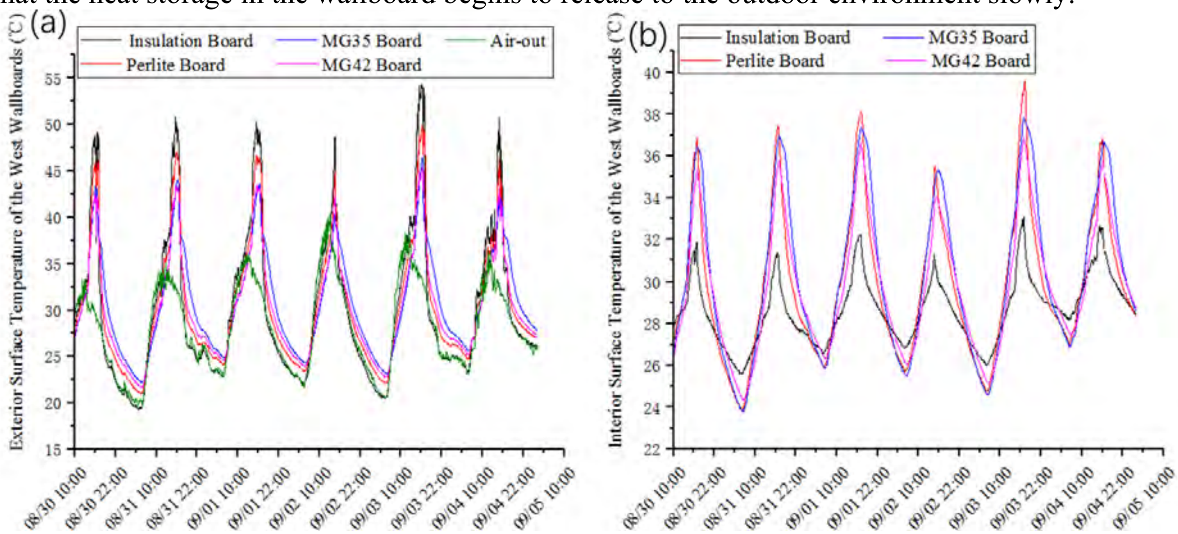

Fig.3 Temperature history curves of the west wallboard: (a) external face; (b) inner face

Table 3. Comparison of the surface temperature of the west wallboards (℃) (Data of September 3).

Type		Polystyrene wallboard (EPS)	Expanded perlite wallboard	MG35 board	MG42 board
Exterior surface	Maximum temperature (℃)/Time	54/16:00	49.5/16:00	46.5/16:20	45/16:20
	Maximum temperature difference (℃)	0	-4.5	-7.5	-9
	Minimum temperature (℃)/Time	20.5/05:22	20.2/05:30	23.2/05:35	22.9/05:30
	Minimum temperature difference (℃)	0	-0.3	+2.7	+2.4
	Temperature fluctuation range in a day (℃)	33.5	29.3	23.3	22.1
Interior surface	Maximum temperature (℃)/Time	33/17:00	39.5/17:11	37.8/16:37	36.8/17:23
	Maximum temperature difference (℃)	0	+6.5	+4.8	+3.8
	Minimum temperature (℃)/Time	26/06:09	24.7/06:21	24.6/06:21	25/06:30
	Minimum temperature difference (℃)	0	-1.3	-1.4	-1
	Temperature fluctuation range in a day (℃)	7	14.8	13.2	11.8
Temperature difference $T_{in\text{-}ex}$ (℃)	Day (Maximum)	21	10	8.5	8.2
	Night (Minimum)	5.5	4.5	1.4	2.1

The maximum temperatures of the inner surface of the four wallboards were in order of the perlite board > MG35 > MG42 > insulation board. This order was different from that of the exterior surface temperatures, and the results were shown in Fig.3(b). The temperature fluctuation of the inner surface of the insulation board was significantly lower than that of other three kinds of wallboards, which means that the insulation board could effectively resist outside heat disturbance. During the daytime, the insulation board has the lowest inner surface temperature among the four wallboards due to its highest thermal insulation, which was in favor of reducing the indoor cooling load in summer. Nevertheless, during the night, the interior surface temperature of the other three wallboards was about 1-2°C lower than that of the insulation board, which indicates that the other three wallboards were easy to release heat to the outdoor environment at night due to their high conductivities. This advantage also benefits for the wallboards storing part of the cold load at night.

Here, we define the temperature difference between the interior and exterior surfaces of the wallboard as T_{in-ex}. During the summer daytime, the larger T_{in-ex} is beneficial for reducing the indoor cooling load, which means the wallboard has good thermal resistance; However, during the summer night, to dissipate indoor heat and wall stored heat to outdoor is necessitous. Therefore, the smaller T_{in-ex} is favor of reducing the indoor cooling load at night. From the Table 3, it can be seen that during the day and night, the T_{in-ex} of the insulation board always bigger than that of other three wallboards. After midnight, the average temperature of both phase change wallboards was lower than the phase change temperature, which indicated that PCMs had completely solidified and the latent heat storage behavior of the material had been completed. Therefore, it can be concluded that the conventional insulation board is more helpful to reduce the indoor cooling load in the daytime, and the PCMs wallboards were more helpful to reduce the indoor cooling load at night.

Results of the east wallboard

When the four kinds of wallboards were installed on the east wall, the temperature history curves of the exterior surface were shown in Fig.4(a). The maximum temperatures of the exterior surface of the four wallboards were in order of the insulation board > MG42 > perlite board > MG35. Comparing with the west wall, the exterior surface temperatures of the MG42 board and the insulation board on the east wall were significantly increased. However, the temperature change trend of the perlite board and the MG35 wallboard on the east wall did not change much. Due to the influence of solar radiation and outdoor air environment, the exterior surface temperatures of the east wall exceeded the phase transition temperature of MG42, so the exterior surface temperature of the MG42 board rise rapidly. Nonetheless, the exterior surface temperature of the west wall was just within the phase transition temperature range of MG42. The process of phase change slowed down the rising rate of temperature. Comparing with the west wall, the exterior surface of the east wallboard was exposed to direct sunlight in the morning, so that the temperature rose rapidly, and the interior surface temperature quickly increased accordingly. As seen in Fig.4(b), the maximum interior surface temperature appeared at about 12 am.

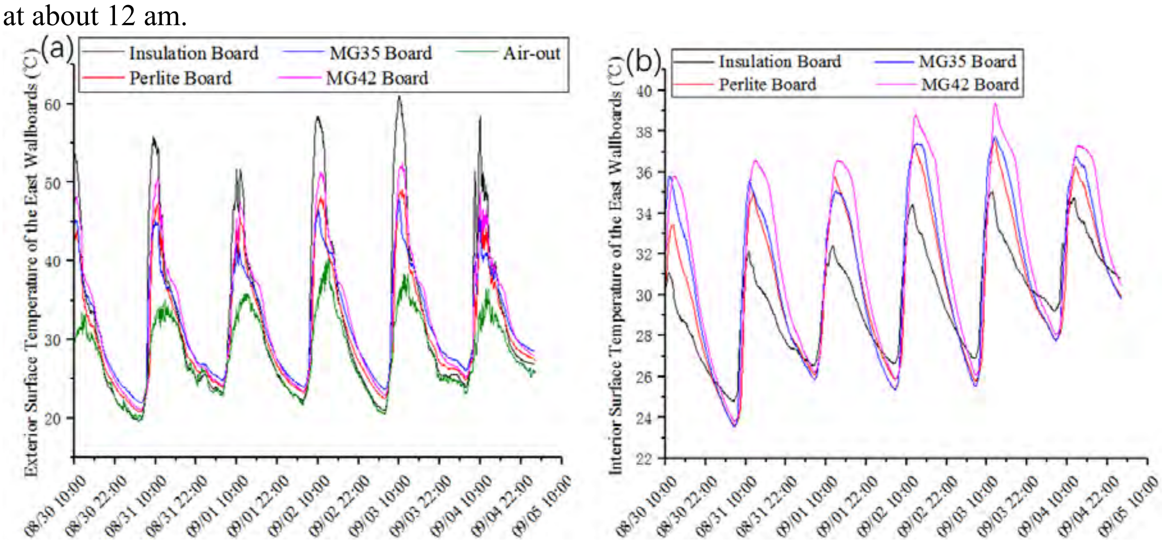

Fig.4. Temperature history curves of the east wallboard: (a) external face; (b) inner face

The influence of the phase transition temperature

When the PCMs wallboard undergoing the phase change process, the temperature rise rate of the wallboard was lower than that of the wallboard was stated in the solid state or liquid. When the PCMs wallboards were applied on the west wall, the largest interior surface temperature of the MG42 board was lower than other wallboards. The probable reason is that the exterior surface temperature of the wallboard on the west wall exceeded the phase transition temperature of MG35 during the daytime, which results in the external part of MG35 board completed the latent heat storage process, and then the temperature rapidly rose. However, when the phase change wallboards were applied on the east wall, the largest interior surface temperature of the MG35 board was lower than other wallboards. The reason is that the interior of MG42 board didn't undergoing the phase change process due to the low internal temperature of the east wall. It can be concluded that when the PCMs wallboards were applied on different direction of the wall should choose different phase-change temperature. Low phase change temperature PCMs is suitable for east wall and high phase change temperature PCMs is suitable for west wall.

CONCLUSIONS

(1) The interior surface temperature of the heat insulation board was the lowest during the daytime, which was good for heat insulation. However, the interior surface temperature of that was the highest during the night, which was unfavorable to the heat dissipation from the room. For the phase change wallboards, although the interior surface temperature of the wallboard was high than that of the heat insulation board, they could store a part of heat during the daytime and store some cold at night. In this study, the minimum interior surface temperature of the phase change wallboard was only 2℃ lower than that of the insulation board, and the cold stored was not noticeable. Although, the phase change wallboards have the advantages for thermal storage performance. The thermal resistance of the phase change wallboards was too small to reduce the indoor cooling load in summer when used on the exterior surface of the wall compared with the conventional polystyrene insulation board.

(2) The suitable phase transition temperature for the wallboard on the east wall and west wall was different from each other. In this study, the exterior surface temperature of the east wall was generally higher than that of the west wall, but the interior surface temperature of the MG35 board was lower than that of the MG42 board. Therefore, the optimal phase transition temperature is not just positively correlated with the outdoor meteorological conditions, but it is also relevant to the scenarios applied.

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