Research on the thermal performance of the phase change material wall prepared by soaking

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Abstract. In this paper, two kinds of phase change material wall were prepared. They were composed of insulation materials and wall materials. The insulation materials were composed of gypsum board and extruded polystyrene board. Gypsum board was made of 70% capric acid and 30% stearic acid. Extruded polystyrene board was made of 65% solid paraffin and 35% liquid paraffin. The method of preparation was soaking. Phase change wall would be compared with ordinary building wall without phase change material. The research focused on the change regulation of the surface temperature and the heat flux when heating as well as stopping heating. This paper attempted to find suitable phase change stored energy pattern used in the building envelope.

1. Introduction

In recent years, building energy efficiency has become the main direction of China's construction industry. Phase change building materials can effectively improve the building energy saving effect, and can reduce indoor temperature fluctuations when they are used for retaining structure. It can reduce operating costs when they are used for air conditioning and heating systems. Therefore, phase change materials have received the widespread attention at home and abroad.

Dorota A modeled and simulated the different types of phase change walls [1]. PSS.Srinivasan et al. simulated and numerically calculated the roof of phase change materials for 365 days [2]. Heim studied the energy-saving effect of the phase change wall [3]. Yang Sheng et al. prepared a kind of foam graphite / paraffin composite phase change thermal storage material, and studied the thermal insulation and temperature control properties of the compound material used as wall enclosure structure [4]. Xu Long et al. studied the influence of composite phase change materials on the indoor thermal environment of lightweight retaining structures. He obtained the conclusion that composite phase change materials can improve the energy saving rate of air conditioning [5]. Zhang Zhengsong et al. proved that the shape stabilized phase change energy storage wall can improve the thermal insulation performance of the building exterior wall in summer through Matlab programming and enthalpy model, and the energy saving effect is achieved [6]. Li Hongjin et al. used Fluent software to simulate the heat transfer performance of shape stabilized phase change gypsum board (PCP) in different positions of heat preservation and different phase change temperature [7]. Ban Xinyu et al. used finite volume method to study the heat transfer problem of building envelope when phase change materials were used [8].
In this paper, the gypsum board soaked with 70% capric acid and 30% stearic acid and the extruded polystyrene board soaked with 65% solid paraffin and 35% liquid paraffin mixture were selected as insulation materials. Two kinds of phase change energy storage building walls were prepared and compared with the common building wall. The change of heat flux and temperature of the three walls is analyzed during heating and stopping heating, and their heat transfer and heat storage performance were compared.

2. Experiment

2.1. Raw materials and main experimental instruments
Raw materials: cement; fine sand; gypsum board; extruded polystyrene board.
Experimental instruments: agilent data acquisition instrument, Agilent34970A (used to measure the temperature of wall); multi point heat flux meter, HFM-215, (used to measure the heat flow through the wall); electric heater; copper-constantan thermocouple; self-made mold.

2.2. Preparation of sample
The size of the wall specimen is 500 mm × 500 mm × 100 mm. The cement and the fine sand were mixed evenly according to the mass ratio of 1 to 2 by the self-made mould. Add appropriate amount of water to the wall, pour the specimen into the mould, and then beat and smooth them evenly. In the gradual solidification, the wall should be covered and watered to maintain maintenance and the curing time was 28 days.

The gypsum board and the extruded polystyrene board were cut into 100 mm × 100 mm respectively. The gypsum board was soaked for one hour in the binary mixture of 70% capric acid and 30% stearic acid at 50 °C. Extruded polystyrene board was soaked for one hour in the mixture of 65% solid paraffin and 35% liquid paraffin at 50 °C. So two kinds of phase change thermal insulation materials were prepared. The heat storage performance of phase change materials is shown in table 1.

| Phase change materials for experiments | Phase change temperature (°C) | Phase change latent heat (J/g) |
|---------------------------------------|-----------------------------|-----------------------------|
| paraffin                              | 66                          | 180.2                       |
| capric acid (CA)                      | 30.5                        | 151.1                       |
| stearic acid (SA)                     | 67.4                        | 239.9                       |

The prepared phase change heat insulation material was pasted on two cement walls specimens respectively, and phase change energy storage wall was prepared. The gypsum board and extruded polystyrene board of the same size without immersion phase change material were pasted on the other two wall specimens. The wall samples are shown in figure 1.

![Figure 1. Schematic diagram of experimental wall structure.](image-url)
2.3. Test process
The wall specimen was placed at least 48 h in the room, so that the inside and outside temperature of
the wall sample was basically the same as the indoor temperature. And then the sample was placed on
the experimental platform. The electric warm air was placed on the side of the wall with to heat the
flow, and heated the wall sample. The other side of the wall was in contact with the indoor air, as
shown in table 2. 350W heat flux was applied on the heating side surface, and the heat flow time was 8
hours. Then the heating flow time was stopped, so that both sides of the wall were cooled naturally at
room temperature. The cooling time was 8h. The repeated experiments were carried out with the four
kinds of wall specimens for three times.

| Experiment number | Test method |
|-------------------|-------------|
| 1#                 | wall with ordinary gypsum board. Gypsum board side is not heated. |
| 2#                 | wall with phase change gypsum board. Gypsum board side is not heated. |
| 3#                 | wall with ordinary extruded polystyrene board. The side of the extrusion plate is not heated. |
| 4#                 | wall with phase change extruded polystyrene board. The side of the extrusion plate is not heated. |

3. Experimental results and analysis

3.1. Thermal performance of gypsum board wall with no heating surface
When the gypsum board side is non heating surface, the experimental results of heat flow and
temperature on the wall surface are shown in figure 2–figure 5.

![Figure 2](image1.png)  ![Figure 3](image2.png)

**Figure 2.** Temperature of non heated surface in the heating stage of gypsum board wall.
**Figure 3.** Heat flow of non heated surface in the heating stage of gypsum board wall.

It can be seen from figure 2 and figure 3 that the temperature and heat flow of ordinary gypsum
wall samples and phase change gypsum wall samples on the non-heated side are not basically
unchanged due to the thermal storage capacity of the cement wall during the first 30 minutes of the
heating. With the continuous heat transfers, the non heated side of the wall is affected, and the
temperature begins to rise gradually. The surface temperature of the non heated side of the phase
change gypsum board wall is almost the same as that of the ordinary gypsum board at two hours
before the heat flux is applied. After two hours, the temperature of the phase change gypsum board
increases gradually. When it reaches the phase change temperature of phase change materials, the phase change materials begin to melt and store the heat. The rising rate of the surface temperature and heat flux about the non thermal side of the phase change energy storage gypsum board wall sample are lower than that of the ordinary gypsum board wall sample. After 5 hours of heat flow, the phase change materials in the phase change gypsum board almost completely melt, and the phase change process is completed. After that, the temperature and heat flux about the non heated side of the phase change gypsum board wall increase rapidly, and the rising rate is higher than that of the ordinary gypsum board wall sample. This is because that the gypsum board absorbs the phase change materials by soaking and occupies most of the microporous structure. The thermal conductivity of the phase change materials [about 0.11 W/(M·K)] is larger than that of the air, which makes the equivalent thermal conductivity of the phase change energy storage materials increase.

From figure 4 and figure 5, it can be seen that the surface temperature and heat flux of the non heated side of the wall sample still increase due to the delayed effect of the wall on the heat flow after stopping heating the wall. The temperature and heat flux on the non heated side of the phase change gypsum board wall reaches the maximum value at about 9 h. The surface temperature and heat flux of the non heated side of the ordinary gypsum board wall reaches the maximum value at about 8.5 h, and the phase change wall has a large delay. After reaching the maximum value, the temperature and heat flux begin to decrease. The phase change materials release heat in the phase change gypsum board wall sample. The temperature and heat flow of non heating side surface are higher than that of the ordinary wall. As time goes on, the difference between them decreases gradually. At the end of the experiment, the temperature and heat flux of the two wall samples are almost the same. In the cooling stage, the temperature and heat flow of the heated side are basically the same, and the difference between temperature and heat flow is very small.

![Figure 4. Temperature of heating surface / non heated surface of gypsum board wall after stopping heating.](image-url)
Figure 5. Heat flow of heating surface / non-heated surface of gypsum board wall after stopping heating.

3.2. Thermal performance of polystyrene board wall

When the extruded plate side is non-heating surface, the thermal performance of the ordinary extruded polystyrene board and the phase change extruded polystyrene board wall is shown in figure 6~9.

Figure 6. Non-heated surface temperature of extruded polystyrene board wall during heating.

Figure 7. Heat flow of non-heating surface of extruded polystyrene board wall during heating.

From figure 6 and figure 7, it can be seen that the effect of heat flow on the heating side has not reached the surface of the non-heated side wall due to the heat storage capacity of the wall. In the first thirty minutes of the beginning of the heating, so that the temperature and heat flow on the non-heated side of ordinary extruded polystyrene wall and phase change extruded polystyrene wall are essentially unchanged. The non-heated side of the wall is affected with the heat transfer, so the temperature and heat flow begin to rise gradually. According to the conclusion of the immersion experiment, the retention rate of the extruded polystyrene board insulation material can reach about 43% for the paraffin mixture. However, due to the density of the extruded sheet is lower than that of the paraffin.
and its interior is a closed pore structure, the phase change materials of the paraffin mixtures is
difficult to penetrate into the interior of the extruded sheet. Therefore, the absolute mass of the phase
change materials in the phase change polystyrene board is small and the effect of phase change
materials is very small, so the change regulation of temperature and heat flow on the non-heated side
of the wall sample and the ordinary wall sample are basically the same during the whole process of
applying heat flow, and the values differ little.

**Figure 8.** temperature of heated surface / non heated surface of extruded polystyrene board wall after
stopping heating.

**Figure 9.** Heat flow of heated surface / non heated surface of extruded polystyrene board wall after
stopping heating.
From figure 8 and figure 9, it can be seen that the curves of the temperature and heat flow of the phase change and ordinary wall samples on the non-heated side and the heated side are basically the same due to the small amount of phase change materials in the extruded polystyrene / paraffin wall sample during the cooling, and the difference is small.

4. Conclusions
(1) In the first thirty minutes of the beginning of the heating, the non heating surface of the wall is not affected by heating, and the temperature and heat flux do not change basically.

(2) When the gypsum board is non-heated side, the increasing rate of surface temperature and heat flow on the non-heated side of the gypsum board decreases after 2 hours of heating. After five hours of heat flow, the phase change materials in the phase change gypsum board melt completely, and the surface temperature and heat flow on the non-heated side increases rapidly. After stopping heating, the temperature and heat flux of the phase change wall on the non heated side are higher than that of the common wall. When the heat side of the wall stops heating, phase change materials will be phase-change in the process of temperature decline and release the stored heat. It makes that the temperature and heat flux of the phase change wall decrease slowly at the beginning.

(3) Because of the closed microporous structure of the extrusion board, the phase change polystyrene board wall can not absorb more phase change materials. So the temperature and heat flux change rules of the non heating side and heating side are basically consistent with the ordinary extruded board wall in the time of heating and stopping the heat flow. Therefore, the phase change extruded polystyrene board materials obtained by direct immersion absorption method have little effect in the wall application.

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References
[1] Dorota A Chwieduk 2013 Energy 59: 301-313
[2] Srinivasan PSS, Ravikumar M 2014 Journal of Mechanical Science and Technology 28(3): 1073-1078
[3] Heim D 2010 Renewable Energy 35(4): 788-796
[4] Yang S, Xu Y, You Y 2012 Journal of material science and Engineering 35(4): 788-796
[5] Xu L, Wang H, Gao Y et al 2013 Architecture Science 12: 45-49
[6] Zhang Z, He J, Zhang B, et al 2012 Architecture Science 6: 102-109
[7] Li H, Cheng J, He J 2013 Journal of Nanjing University of Technology: Natural Science Edition 7: 115-120
[8] Ban Y, Wang Q, Zhan N 2013 Energy conservation 3: 42-45