Journal of Civil, Construction and Environmental Engineering
2022; 7(4): 81-85
http://www.sciencepublishinggroup.com/j/jccee
doi: 10.11648/j.jccee.20220704.15
ISSN: 2637-3882 (Print); ISSN: 2637-3890 (Online)

The Effect Study of Organic Phase Change Materials Applied to Building Exterior Walls

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To cite this article:
Wang Qingwu. The Effect Study of Organic Phase Change Materials Applied to Building Exterior Walls. *Journal of Civil, Construction and Environmental Engineering*. Vol. 7, No. 4, 2022, pp. 81-85. doi: 10.11648/j.jccee.20220704.15

Received: June 18, 2022; **Accepted**: July 4, 2022; **Published**: July 20, 2022

Abstract: Phase change material (PCM) can change its physical state (such as solid solid, solid liquid, etc.) with the temperature difference between environment and material as the driving force within a certain temperature range, so as to realize heat storage or heat release. This heat storage characteristic makes its application in building energy conservation, such as building envelope, have a very broad prospect. Porous matrix composite phase change materials have a high latent heat of phase change. The thermal energy storage based on phase change materials can more effectively solve the problem of building energy supply and demand mismatch. In order to study the thermal insulation effect of phase change energy storage composites on buildings, organic phase change materials were prepared, and inorganic materials were used as the supporting materials of phase change materials. The thermal and mechanical properties of the composite phase change materials were measured. In the research, an experimental room was built, and the composite phase change materials were applied to the experimental room for experiments and simulation analysis. The results show that the prepared composite phase change materials have appropriate phase change temperature and large latent heat value. The phase change room can delay the time of peak temperature, reduce room temperature fluctuations, and improve living comfort. After many cold and heat cycles, the phase change temperature and latent heat value of the phase change material basically change little, which has good thermal stability and can be used for building insulation.

Keywords: Organic Phase Change Energy Storage, Thermal Insulation, Gypsum Board

1. Introduction

At present, sensible heat storage technology is widely used in buildings for thermal insulation, but sensible heat storage materials have small heat storage capacity, which is easy to cause indoor temperature fluctuations. The thermal energy storage system based on phase change materials can more effectively solve the problem of mismatch between energy supply and demand, and is a more promising heat storage technology [1-3]. Latent heat storage materials, i.e. phase change materials (PCM), have the advantage of high energy storage density. They can absorb or release a large amount of energy during phase change. Combining them with buildings for appropriate design can increase the thermal quality of buildings, improve indoor thermal comfort and reduce heating, ventilation and air conditioning systems. Therefore, the use of energy can be more reasonable [4-8].

The porous matrix composite PCM has a high latent heat of phase change. The inorganic material with a microporous structure with a large specific surface area is used as the supporting material, and the liquid organic or polymer phase change heat storage material (higher than the phase change temperature) is sucked into the micropores through the capillary action of the micropores to form an organic / inorganic composite phase change heat storage material. In this material, when the organic or polymer phase change heat storage material has a solid-liquid phase change in the micropores, Due to the capillary adsorption force, the liquid phase change heat storage material is difficult to overflow from the micropores, which makes PCM lose its fluidity in the macro and show solid-solid phase transition. However, it is still in the form of solid-liquid phase transition in the micro. This kind of PCM does not need a container and increases the heat transfer area and heat transfer efficiency. It can be made into various shapes or composite into other materials as required.

2. Phase Change Material Properties

2.1. Preparation of Phase Change Materials

The selection of phase change materials should integrate the properties of chemistry, thermodynamics, dynamics and economy. In this paper, organic acids are used as phase change materials. Several common organic acids, such as stearic acid, lauric acid and capric acid, have melting points and phase change temperatures: the melting point of stearic acid is about 47°C, and the phase change temperature is about 59°C; The melting point of lauric acid is about 42°C, and the phase transition temperature is about 47°C; The melting point of capric acid is about 27°C, and the phase transition temperature is about 31°C. The phase transition temperature of capric acid and lauric acid is close to the ambient temperature, and they have good heat storage capacity and strong practicability. However, their phase transition temperature is higher than the habitable temperature 21°C, and the melting point needs to be reduced. According to the principle of low eutectic point, the two substances are mixed in a certain proportion to reach the expected phase transition temperature range [9, 10]. Finally, the mass ratio of the main energy storage substance (lauric acid: capric acid) is determined to be 3:7, and the phase transition temperature reached is 21.3°C. Then choose the traditional building materials to compound into PCM building materials, here choose gypsum and silicon bath soil. With the increase of PCM composite material content, the energy-saving effect of PCM gypsum building materials becomes greater, but its mechanical strength and thermal stability will decline. Therefore, the PCM composite material content should not be too high. PCM is compounded with hemihydrate gypsum powder and diatomite to make PCM gypsum board. The PCM dosage is 16%.

2.2. Thermal Characteristics and Thermal Reliability of PCM

Figure 1 and Figure 2 show the differential scanning calorimeter (DSC) curve of PCM composite, which shows the specific heat capacity, phase transition temperature and latent heat value of PCM composite. There are endothermic and exothermic peaks during melting and solidification. The melting temperature is 22.2°C, and the melting enthalpy is 116.7 J/g. After 500 cold and hot cycles, the melting temperature of the composite phase change material becomes 21.7°C and the melting enthalpy is 110.7 J/g. The solidification temperature is 24.8°C and the solidification enthalpy is 114.1J/g. After 500 cold and heat cycles, the solidification temperature becomes 24.3 and the solidification enthalpy becomes 105.2J/g. After cycles, the phase change temperature and latent heat value of the composite phase change materials change little, and the composite phase change materials have good thermal stability. It can be used as building materials.

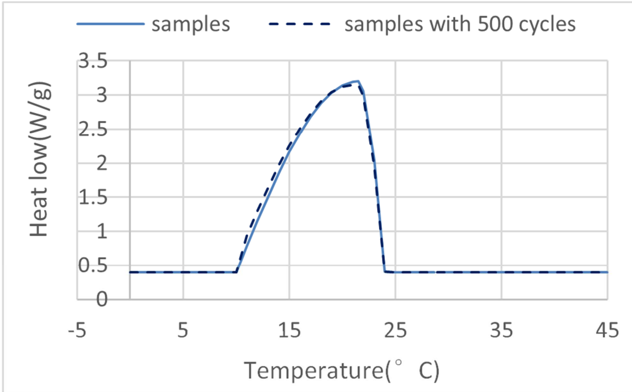

***Figure 1.** DSC curve of phase change material.*

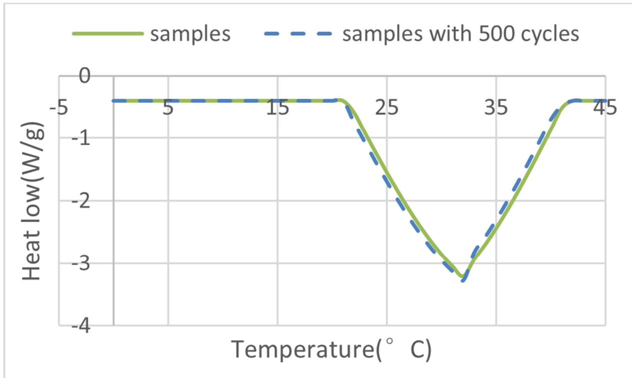

***Figure 2.** DSC curve of phase change material.*

2.3. Mechanical Properties of Phase Change Materials

According to the requirements of Chinese national standard GB/T176167.3-1999, the size is 40mm × 40mm × 160mm samples were tested. The mechanical load rates of flexural strength and compressive strength tests are 50 ± 10N/s and 2.4 ± 0.2 kN/s respectively. Each mechanical strength value is the average of three samples. The compressive strength of the energy storage gypsum material is 18.80MPa and the flexural strength is 5.00MPa.

***Table 1.** Thermo-physical properties of the materials.*

Material	density kg/m^3	thermal conductivity W/(m ·k)	specific heat J/(kg ·k)
Common gypsum board	971	3.7	2688
PCM gypsum board	810	0.35	1100
Brick wall structure	669	0.114	1050
PVC board	1287	0.19	1018

3. Phase Change Material Laboratory

3.1. Structure of Laboratory Room

An experimental room was built for testing. The internal space of the experimental room was 2000mm long, 2000mm wide and 2000mm high. The outermost layer of the laboratory is made of 8mm thick ordinary gypsum board, and the secondary layer is made of 8mm thick PCM gypsum board. The inner layer is made of 240mm thick brick wall structure. The average density of brick wall structure is 669kg/m^3, the thermal conductivity is 0.114W/(m·K), and the specific heat is 1.05kJ/ (kg · K) Common gypsum board, PCM gypsum board, PVC board shall be used for floor and roof, with a thickness of 50mm.

At the same time, a room without phase change board is built as the reference room. Instead of PCM gypsum board, ordinary gypsum board is used in the reference room. The thermophysical properties of the materials used are shown in Table 1.

3.2. Climatic Conditions of the Laboratory

Room heating conditions are carried out by applying artificial climate. The outdoor comprehensive temperature of Baoding summer climate is selected as the temperature cycle program of artificial climate. The comprehensive outdoor temperature can be referred to literature [11], which is mainly affected by outdoor air temperature and solar radiation. The solar radiation intensity and outdoor comprehensive temperature of Baoding in summer are shown in Figure 3.

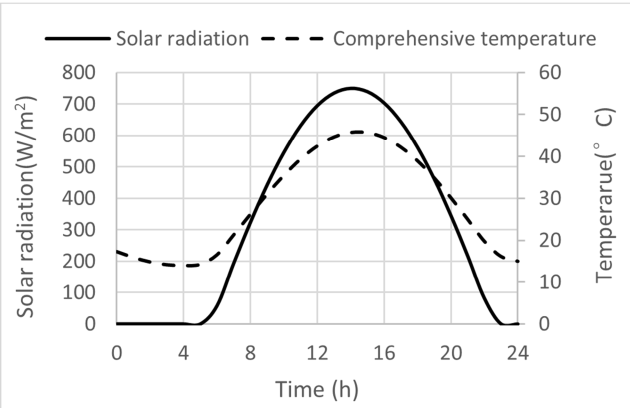

Figure 3. *Solar radiation and temperature in a summer day.*

3.3. Thermal Performance of Test Room

Thermocouples are pasted at the center of each wall surface of the laboratory room to detect the temperature. A value is recorded every 5 minutes. The detected temperature is averaged to obtain the curve of the temperature of the inner surface changing with time. Figure 4 shows the curve of the external ambient temperature and the inner wall temperature of the reference room and the phase change room with time. It can be seen that with the periodic change of artificial climate temperature, the temperature of reference room and phase change room changes periodically.

The maximum and minimum temperature of the artificial climate chamber are 45.8 and 13.5°C respectively, and the temperature change range is 32.3°C. For the reference room, the maximum and minimum temperature of the inner wall of the room are 37.3°C and 18.1°C respectively, and the temperature change range is 19.2°C, which is 13.1°C lower than the temperature amplitude of the artificial climate box. This is mainly due to the thermal inertia of the insulation layer outside the wall. In addition, the maximum temperature of the reference room occurred for 17.1 H. The change range of the phase change room is smaller than that of the reference room. This is mainly because the composite phase change material can absorb a large amount of heat energy when it melts in the daytime, and release the stored heat when it solidifies at night. Therefore, capric acid, lauric acid / gypsum and silica bath soil composite phase change materials can reduce the fluctuation of indoor temperature and improve indoor comfort.

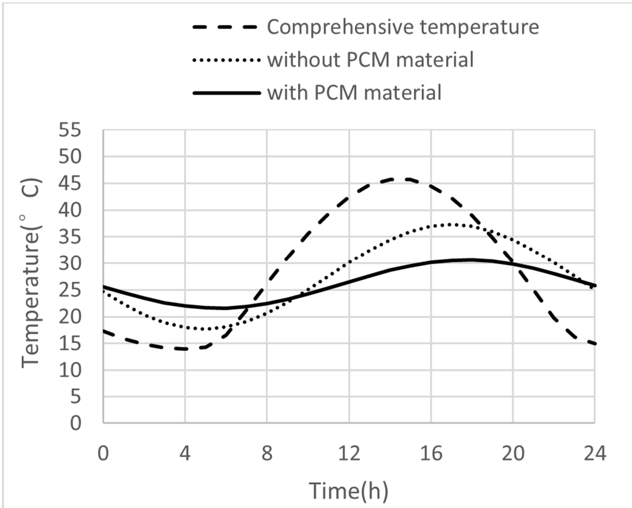

Figure 4. *Temperature time-histories of the exterior environment.*

3.4. Simulation Analysis of Laboratory

In order to simplify the numerical calculation, the following assumptions are made for the calculation model: (1) only convective heat transfer and conduction heat transfer are considered,; (2) All materials are isotropic; (3) The thermophysical properties of the material will not change with the change of temperature.

The initial condition of the room model is that the temperature in the room is taken as the uniform initial temperature. The outside temperature of the room changes with time due to the influence of solar radiation and outdoor air. The outer surface boundary condition of the room model is the convective heat transfer between the outside temperature and the outside surface temperature of the room, and the inner surface boundary condition is the convective heat transfer between the inside surface temperature and the air temperature in the room. The wall temperature distribution of the experimental room at a certain time obtained by simulation is shown in Figure 5.

3.5. Comparison Between Experimental Results and Simulation Results

Figure 6 shows the comparison between the experimental and simulated values of the inner wall temperature of the reference room and the phase change room. It can be seen from the figure that the variation trend of the experimental and simulation results is basically the same. At this time, the surface heat transfer coefficient in the simulation process is set to 21 w/ (M2·K). For the reference room, the average relative deviation between the experimental value and the simulated value is 6.4%, the difference between the peak temperature is about 0.6°C, and the occurrence time of the simulated value peak temperature is delayed by 50min. For the phase change room, the average relative deviation between the experimental value and the simulation value is 3.2%, while the difference between the peak temperature is about 0.5°C. The time when the simulation value peak temperature appears is delayed by 30min. In general, the experimental results are in good agreement with the simulation results.

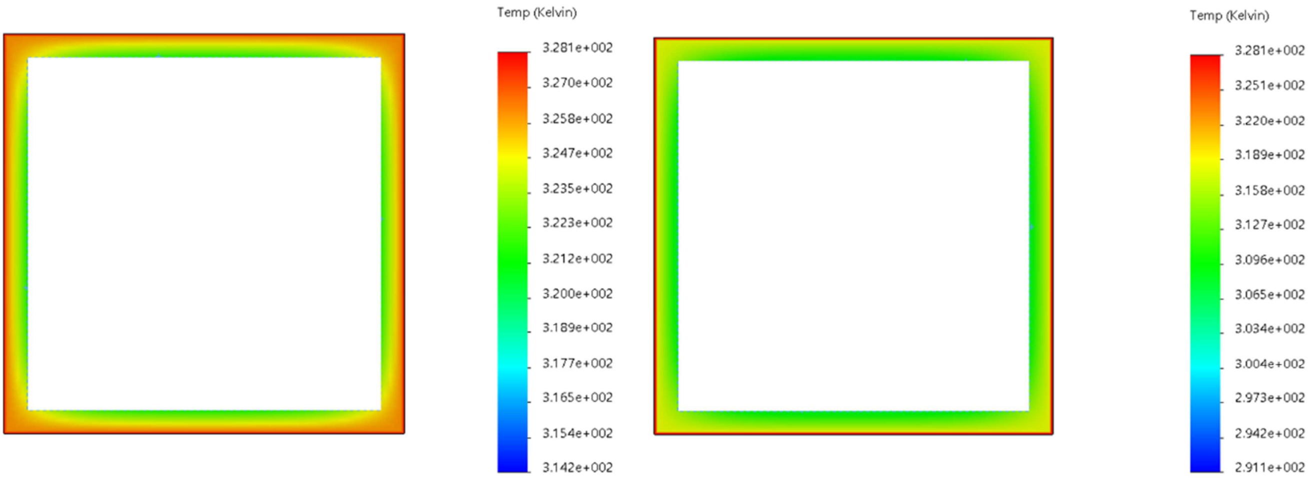

Figure 5. *Comparison of calculation results with and without PCM.*

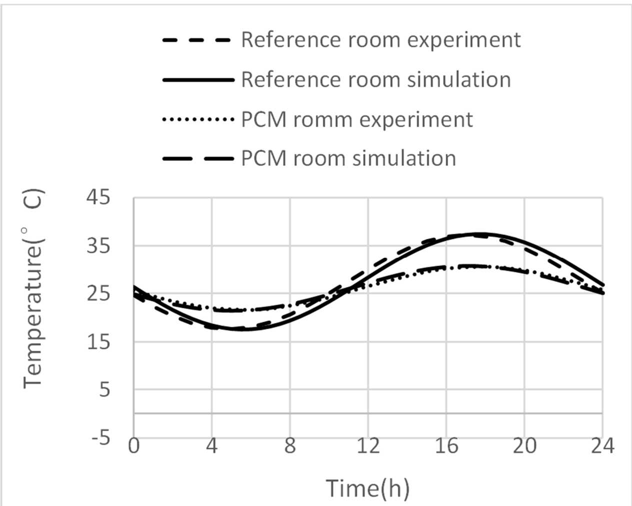

Figure 6. *Experimental results versus numerical values.*

4. Conclusion

In this paper, organic composite phase change materials are applied to building exterior walls, and experimental research and simulation analysis are carried out. Firstly, capric acid, lauric acid / gypsum and silica bath soil composite phase change materials were prepared, and their thermal and mechanical properties were tested; Combined with the wall structure to build the experimental room, the thermal performance of the experimental room was tested; A numerical model was established to analyze the thermal properties of the room with and without composite phase change materials. The prepared composite phase change materials have suitable phase change temperature and large latent heat value, and are suitable for building exterior walls; After 500 cold and heat cycles, the phase transition temperature and latent heat value of the composite phase change materials have little change, and have good thermal stability; Phase change room can delay the time of peak temperature, reduce room temperature fluctuation and improve living comfort; The average relative deviation between the experimental results and the simulation results is small, the agreement is good, and the numerical model is reliable.

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