Journal of Ovonic Research Vol. 14, No. 1, January - February 2018, p. 35 - 47

RESEARCH ON THERMAL ENERGY STORAGE AND RELEASE CHARACTERISTICS OF FOAM ALUMINUM PARAFFIN COMPOSITE PHASE CHANGE MATERIALS

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In this paper, the FLUENT software is adopted to carry out numerical simulation for the temperature distribution of the building envelope blending with mixed phase change materials and composite phase change material under winter condition. The foam aluminum/paraffin composite phase change material is placed in the wall structure, the experimental study was used to reach on thermal energy storage and release characteristics of composite phase change wall, and the effect of phase change walls on the channel and the room, to test the practicality of composite phase change materials, and through the experimental research and numerical simulation. It shows that, when the composite phase change material is added into the wall, the temperature variation in the room is decreased, and the temperature is delayed; With the heat transfer performance of the wall is better, the room's temperature is lower, the thermal conductivity of the material is good for the wall thermal insulation; there is a certain error between the experimental value and the simulated value.

(Received October 26, 2017; Accepted January 11, 2018)

Keywords: Paraffin, Foamed aluminium, Solar buliding ,Composite phase change material, Heat transfer property

1. Introduction

As a kind of typical phase change thermal storage materials, paraffin is characterized by large phase change latent heat, and no super-cooling, good stability and low price[1], with different mass ratio by mix up low melting liquid paraffin with high melting solid paraffin were studied experimentally to choose the phase change temperatures fluctuates between 20~30 ℃ and latent heats is larger as heat storage material of building wall[2].

But paraffin has a disadvantage of low thermal conductivity, to improve the storage/exothermic capacity of paraffin in the heat storage system, domestic and foreign experts have conducted a number of studies. HC. Min[3] research shows that using PCM-based materials in roof finishing materials can reduce surface temperatures and improve thermal comfort. Hua Wei san et.al[4] research that the nano iron for effective heat transfer enhancement. Zhang X et.al[5] research that PA-CNTs/EP FS-CPCMs exhibit good chemical and thermal stabilities. And demonstrate considerable potential as thermal energy storage materials. Şahan N, Paksoy H[6]. research that the nano tubular-zinc oxide is used as an additive with 10%wt composition to paraffin to prepare a nanocomposite. The variations in thermo physical properties of paraffin in

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composite form were subjected to investigate by experimentally. H. Zou et.al[7] results show that the heat storage and heat release rate of the composites increase with the addition of porous nickel, and the composite has a high salt content and a large heat storage density. So far, there are mainly includes the following four aspects to improve the heat storage capacity of paraffin storage system[8]: Enhancement of heat transfer by adding fins; Enhancement of heat transfer by adding graphite; Enhancement of heat transfer by adding graphite metal.

The phase change energy storage technology has been applied in many fields, such as solar thermal utilization, waste heat utilization and (more than) in the field of construction (including construction of air conditioning and heating), the application of passive solar house agricultural greenhouse, daily necessities, household heating and heat recovery, aerospace and other fields. It should be said that the theory and application of phase change energy storage is a new discipline which is rooted in many interdisciplinary fields. It has profound significance and value in the utilization of new energy and energy saving technology research[9].Species, phase change material selection principle was studied[10]. The application method of phase change materials with the building as well as phase change materials in building cooling and heating field were summarized systematically. Pasupathy et.al[11] propose a new type of residential building with two layers of phase change material. The test results show that the double layer phase change material can effectively reduce the variation of indoor temperature. However, there is not much research on the application of phase change thermal storage materials to buildings to improve the building insulation and energy saving effects.

With the rapid development of materials technology to the aluminum foam as a porous matrix, filled with suitable temperature close to the melting point of mixed paraffin, preparation of aluminum foam / paraffin composite phase change materials (Foam aluminum / paraffin composite phase change material, referred to as FAPC, a phase change material) surface of the foam aluminum can be used as a storage base paraffin phase change material, the other foam aluminum can improve the thermal conductivity of paraffin as additives. This paper uses the method of numerical simulation and experimental study of the combination of FAPC, The heat storage properties were studied about phase change material thermal conductivity and latent heat, and the analysis of the FAPC phase change material under winter condition, building materials with heat storage characteristics in the wall, and the influence of temperature on the channel and storage wall of the room. And the results of the two methods were compared and analyzed, in order to test the practicability of the aluminum foam / paraffin composite phase change material.

2. Experiment

2.1 Arrangement of test room and temperature measuring points

A 1.5 m × 1.8 m × 4 m passive solar laboratory was constructed, as shown in figure 1. It is divided into two layers, the specific size of the two layer, as shown in figure 2. The main structure is steel structure, south walls of 5 mm toughened glass wall, the wall with steel wall. Based on the direct immersion method[12] to prepare composite phase change materials, the FAPC phase change material with porosity of 98%, pore density of 0.3 g/cm^3 and pore diameter of 0.8 mm was prepared. The FAPC phase change materials provided by Suzhou gassider foam metal limited liability company, as shown in figure 3. The prepared 1.2 m × 0.6 m × 0.02 m FAPC phase change material is placed on the south wall of the lower layer of the experimental room, and vents are arranged at the upper and the lower parts of the laboratory, The upper layer of the experimental room was used as the control group.

Fig.1 Laboratory room photos

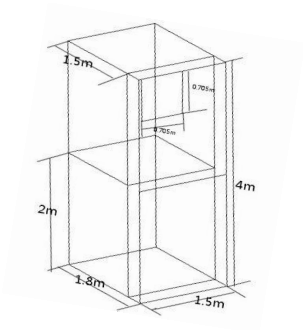


Fig.2 Specific size of the experimental room

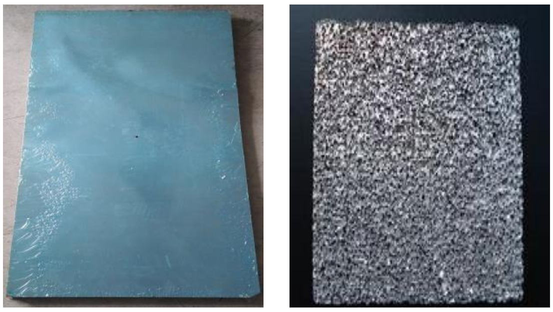


Fig.3 Foamed aluminum board

The temperature sensor is arranged in the thermal channel, the south wall surface, the inside of the south wall and the two rooms. The arrangement form is shown in figures 4-6. 02, 16 and 18 are temperature measuring points along the direction of the thermal channel width. Among them, 02 are arranged on the right (East) near the wall surface, 16 are arranged in the middle position of the hot wall, 18 are arranged in the left (west wall); 10, 16 and 07 are temperature measuring points along the direction of the thermal channel. Among them, 07 are near the upper wall, 16 are near the hot wall, and the No. 10 is near the lower wall; 11 and 20 are respectively the point for measuring temperature of the upper and lower two rooms, the 04 is the point for measuring temperature of the middle of the north wall surface, 01, 02 and 03 are respectively the point for measuring temperature from the inside of the south wall to the exterior.

Fig.4 Arrangement of temperature points in the channel

a) on the first floor *b) on the second floor*

Fig.5 Arrangement of temperature points in room thermom

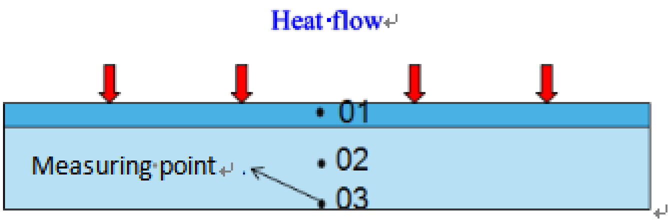


Fig. 6 Arrangement of temperature points inside the south wall

2.2 Experimental device and measurement method

The main parameters of this experiment are temperature, wind speed and solar radiation, and the instruments used mainly include: Agilent, 34972a data acquisition, intelligent wind and air volume meter, high-precision wind meter, thermocouple, thermometer, solar radiometer.

Before the experiment, in order to ensure that each thermocouple in the experiment is under the same temperature baseline, the T thermocouple is placed in boiling water (100℃) to calibrate the water bath temperature, and two times are determined and checked. The three experimental data are processed, and the deviation value is calculated. Then the software is used to correct the thermocouple.

2.3 Results and discussion

Under winter (11.25~11.27) conditions, the influence of the south wall on the indoor temperature was analyzed. In the phase change material solar house and ordinary material solar house indoor temperature monitoring points, monitoring temperature changes, as shown in figure 5, respectively 20 and 11, and the temperature change trend is plotted as figure 7.

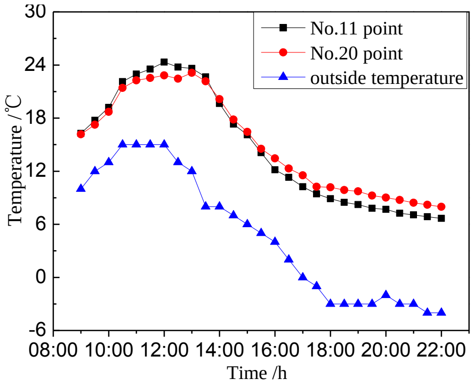


Fig. 7 Comparison of temperature between the phase change material solar room and the ordinary material solar room in winter

The temperature difference between the phase change material solar house and the ordinary material solar house is 14 and 17, respectively. The addition of phase change material can obviously improve the temperature fluctuation; The temperature of ordinary materials solar house reached 25℃ at 13 noon, and the maximum indoor temperature of the phase change solar house is about 1℃ lower than that of the ordinary room; After 4 p.m., the phase change material solar house temperature is gradually higher than the ordinary material solar house, the highest is about 2℃.The phase change material solar house is delayed about 1 hours longer than the peak temperature time of the ordinary material solar house, thus avoiding the peak of the electricity consumption.

As illustrated in Figure 8, during the day, when the outdoor temperature is higher than the melting point of the phase change material, part of the heat passes through the wall into the room, while the other is stored by the phase change material.

The outer surface of the south wall of the phase change material reaches the maximum temperature at 1 p.m., about 26℃, and the temperature of the inner surface is 22℃,that is, the maximum temperature is decreased by about 4 degrees, and the time is delayed for about half an hour; The temperature of the wall that close to the outdoor part (that is, the No. 1 point position) changes most, and the closer the room is, the more slowly the temperature changes. That is to say, the storage capacity of the phase change wall can reduce the range of indoor temperature change to a certain extent.

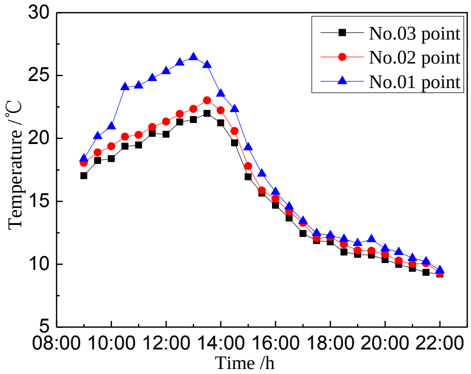


Fig. 8 Temperature variation in the south wall of the phase change room

3. Numerical Simulation analysis of phase change wall

Using FULENT simulation software, a two-dimensional full scale model is abstracted, the paraffin / foam aluminum composite phase change material was applied to the whole wall, the room temperature of solar house with composite phase change material was numerically simulated and compared with the actual experiment.

3.1 Build physical models

The FAPC phase change material is placed in the whole south wall of the laboratory, and vents are arranged at the upper and lower parts of the laboratory, and the experimental room with shaped phase change material was used as the control group. To study the effects of adding storage materials on the rooms, the wall and the thermal channel temperature change trend. In the simulation part, respectively by shape-stabilized phase change wallboard wall, composite phase change wallboard, hot channels and the room area is calculated, under the same conditions, the temperature distribution and phase change material liquid fraction changes on the two wall, hot channel, room area were numerical simulation of unsteady coupling. The model is shown in Fig. 9.

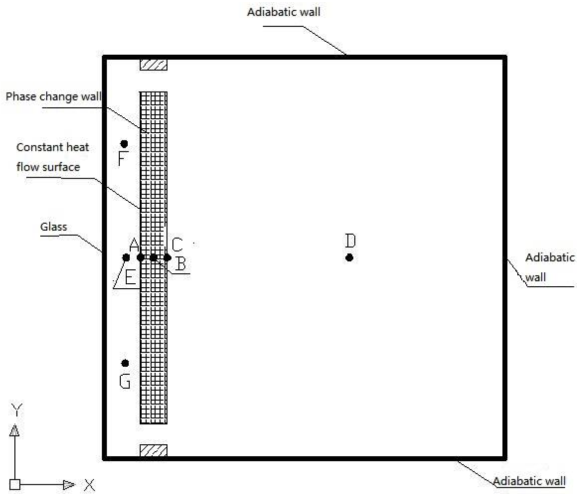


Fig.9 The room model

3.2 Build mathematical models

To consider convenience, make the following assumptions about the model:

(1)the paraffin wax is pure and isotropic and has phase transition in a certain range of temperature;

(2)The fluid after melting is a Newton fluid, incompressible, and the density consistent with the Bounssinesq hypothesis;

(3)Air belongs to fluid, phase change wall is solid, and their contact part belongs to fluid solid coupling heat exchange;

(4)In the two-dimensional simulation, it is assumed that the thickness is 1 m, the heat flux that applied to the phase change wall is 500 W/m2, and the volumetric heat source as follows, $q = \frac{P(\mathrm{W})}{V(\mathrm{m}^3)}$,The wall height is 1400 mm, and the length is 20 mm. Then the volume heat source as follows:

$$q = \frac{P}{V} = \frac{500 \times 1.4 \times 1}{1.4 \times 0.02 \times 1} = \frac{500}{0.02} = 25000 \ \ \mathrm{W/m^3}$$

Using Gambit software to model and mesh, and quadrilateral mesh is selected.

In order to get better solidification / melting of paraffin phase change material, and air flow, using 2D implicit, non steady state, and the pressure based solver, choose energy equation, standard k-ε turbulence model and Solidification/Melting model on numerical simulation.

According to the hypothesis of the physical model described above, the basic theory of solidification / melting is simulated by FLUENT, and a specific mathematical model is established.

Since the effect of convection is not considered, so the equations are energy equations.

$$X_1 \le x \le X_2$$

According to the volume average theory:

$$\varepsilon = \frac{V_{\mathrm{PCM}}}{V} \tag{1}$$

$$\gamma = \frac{V_1}{V_{\mathrm{PCM}}} \tag{2}$$

In the formula: V_{PCM} —phase change material, m3
V_1 —volume of liquid phase change material, m3
V —total volume, m3
In the wall with phase change material,the energy equation as follows,

$$\frac{\partial}{\partial \tau}\left[\varepsilon\left(\gamma\rho_1 H_1 + (1-\gamma)\rho_s H_s\right) + (1-\varepsilon)\rho_g H_g\right] = \nabla\cdot\left(\lambda_{\mathrm{eff1}}\nabla T\right) \tag{3}$$

There is no phase change material in the wall, and the energy equation as follows,

$$\frac{\partial}{\partial \tau}\left[\varepsilon\rho_k H_k + (1-\varepsilon)\rho_g H_g\right] = \nabla\cdot\left(\lambda_{\mathrm{eff2}}\nabla T\right) \tag{4}$$

when $\rho_s = \rho_1 = \rho$, equation 1-3 was simplified as follows,

$$\frac{\partial}{\partial \tau}\left[\varepsilon\left(\gamma\rho\ (H_1 - H_s) + \rho\ H_s\right) + (1-\varepsilon)\rho_g H_g\right] = \nabla\cdot\left(\lambda_{\mathrm{eff1}}\nabla T\right) \tag{5}$$

Equation (4), (5),
λ_{eff} —Equivalent thermal conductivity, $\mathrm{W/m\cdot K}$
ε —Porosity of porous media, %
γ —liquid fraction, %
λ_1, λ_s —Liquid phase / solid phase thermal conductivity, $\mathrm{W/m\cdot K}$
λ_g —Thermal conductivity of skeleton, $\mathrm{W/m\cdot K}$
H_1, H_s —Enthalpy of liquid / solid phase change materials, kJ/kg
H_g —The enthalpy of the skeleton, kJ/kg
ρ_1, ρ_s — liquid / solid phase change material density, kg/m3
ρ_g — skeleton density, kg/m3
Equivalent thermal conductivity as follows:

$$\lambda_{\mathrm{eff1}} = \varepsilon\left[\gamma\lambda_1 + (1-\gamma)\lambda_s\right] + (1-\varepsilon)\lambda_g \tag{6}$$

$$\lambda_{\mathrm{eff2}} = \varepsilon\lambda_k + (1-\varepsilon)\lambda_g \tag{7}$$

λ_k —Air thermal conductivity, $\mathrm{W/m\cdot K}$
Boundary condition:

In the process of melting, Constant heat flow surface：

$$-\lambda \frac{\partial T}{\partial x} = q \quad , \quad \tau > 0 \qquad x = X_1 \tag{8}$$

Other wall heat insulation：

$$\frac{\partial T}{\partial x} = \frac{\partial T}{\partial y} = 0 \tag{9}$$

3.3 Parameter setting

In the process of solidification, natural cooling is adopted, and the initial temperature as the ambient temperature is used .

At the initial stage, the phase change wall, the room and the ambient temperature are set to T0. With the constant input and output of the surrounding heat, the temperature of the phase change wall and the two area of the room will reach equilibrium state.

The simulation process is divided into accumulation of heat and heat release. The heat storage time of the wall is 08:00~16:00 (Using daytime light, the area may vary at different times). The system initialization temperature is 18 ℃in simulation, the time step is 10s, and the number of steps is 2880 in simulation. The heat release time is 16:00~08:00, and the 4th wall is set as adiabatic condition. The wall temperature after the end of heat storage is taken as the initial condition, the time step is 10 s, and the calculation step is 5760.According to the literature [13], the parameters used in the calculation are shown in table 1-2:

Table 1. Parameter set value of phase change material

Name	size	unit
density	ρ_1=ρ_2=783	kg/m^3
phase transition temperature	t=15~48	℃
Specific heat	c_P=0.871	kJ/(kg·k)
Thermal conductivity	λ_s=0.235,λ_l=0.154	W/m·K
Phase change latent heat	γ_{PCM}=65.86	kJ/kg
Outdoor heat transfer coefficient	h_{out}=20	W/m^2·K
Indoor heat transfer coefficient	h_{in}=15	W/m^2·K

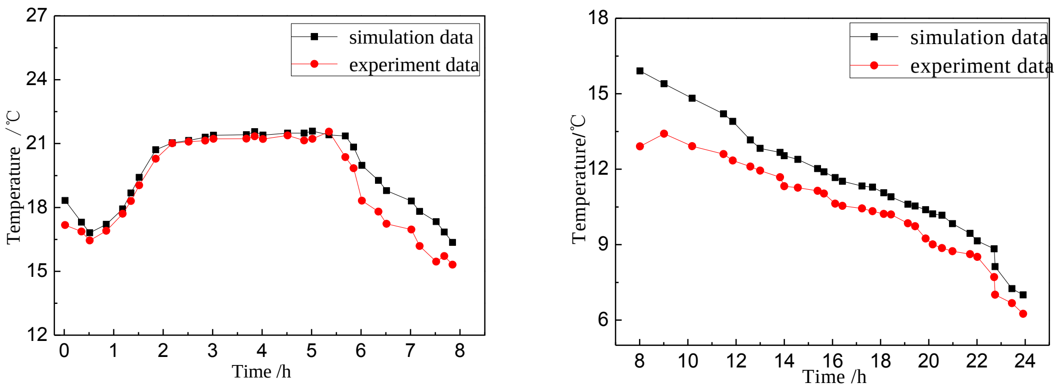
Table. 2 Parameter set value of foam aluminum

Name	size	unit
Porosity	ε=98	%
Density	ρ=3000	Kg/m^3
Specific heat	c_P=0.871	kJ/(kg·k)
Thermal conductivity	λ=237	W/m·K

3.4 Comparison between simulation and experiment

Fig.10 (a) and (b) are comparison between the simulated temperature and the experimental values of the D center temperature of FAPC phase change solar house in the process of melting and solidification. As can be seen from the diagram, the simulated values of indoor temperature coincide with the experimental values at the initial stage, and the trends are the same. Because the simulation delay time of phase change process is more than the actual experimental, there is an error at the end of phase transition. And the actual experiment can not be completely adiabatic, the measured temperature of the indoor temperature is always lower than the simulated value, but the maximum error is not more than 9%, to meet the actual requirements.

As shown by the diagram, in the case of natural cooling, the actual experiment can not be completely adiabatic, the measured temperature of the indoor temperature is always lower than the simulated value, but the maximum error is not more than 18%, to meet the actual requirements.



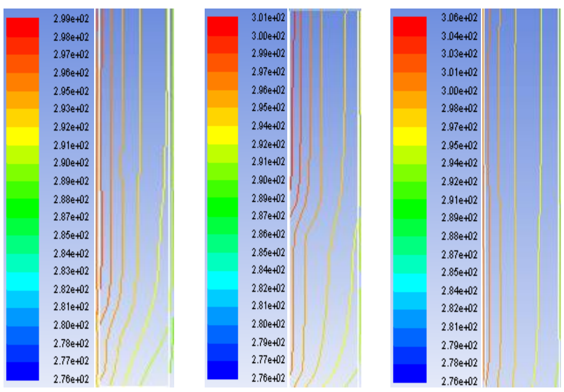
(a) (b)

Fig.10 Simulation and experimental values of point D in melting and solidification

To sum up, the simulation results of the foam aluminum / paraffin composite phase change material in the whole south wall are very different from the actual experiment, meet actual requirements. That is to say, the simulation method is correct.

3.5 The analysis of simulation results

Figure 11 and 12 were compared the change trend of temperature inside the wall in the melting process of south wall were implanted with shaped phase change material and composite phase change material. The left side indicates the temperature according to the color difference, and the temperature distribution inside the wall is on the right.



t = 2h t = 4h t = 7h

Fig.11. Temperature field of melting in the shaped phase change wall

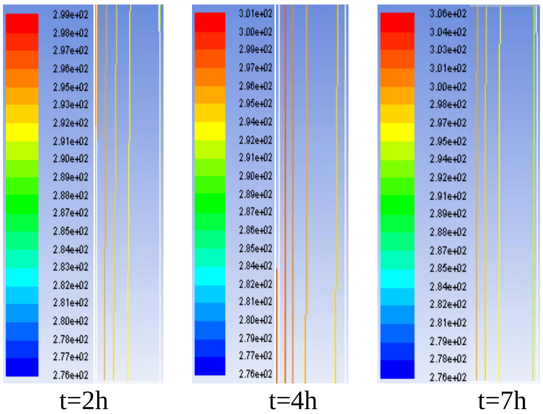
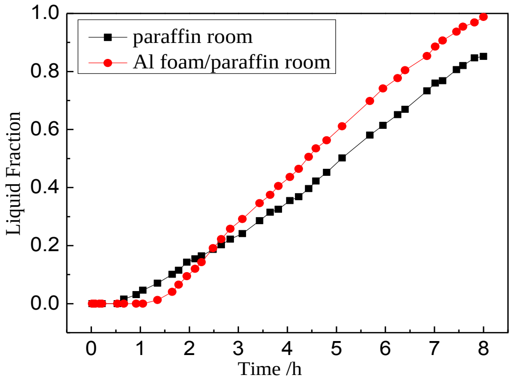


Fig.12 Temperature field of melting in the composite phase change wall

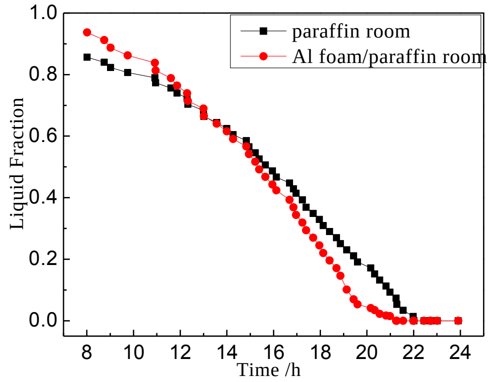
As can be seen from the diagram, due to the poor heat transfer performance of the polyethylene / paraffin storage wall, there is a phenomenon of heat accumulation, which is characterized by uneven temperature distribution.The aluminum foam / paraffin composite PCM Wallboard, the excellent heat transfer performance of the foam aluminum enables the heat energy to transfer rapidly from the heating surface to the heat flow direction, the heat transfer performance of the whole storage wall is improved, the temperature distribution is more uniform, and the heat transfer time is shortened. Foam aluminum, as a porous medium, has its own characteristics. It belongs to the flow problem in porous media, also known as porous osmosis. Inertial resistance and viscous resistance affect the flow. Therefore, the isotherms are shown to be more regular.

Fig. 13（a）and（b） show the change of liquid volume fraction with time in the porous medium layer of the phase change wall and the composite phase change wall during melting, it can be seen from the figure a, the slope curve of composite phase change wall liquid volume fraction changes with time is far greater than the composite phase change wall, so the melting speed of composite phase change wall is far greater than the shaping phase change wall. Because the heat transfer performance of the phase change wall is poor, a large amount of heat is gathered in the local part of the system. The temperature increases rapidly to the melting point, while the composite phase change material has good heat transfer performance, and the overall temperature distribution is even.

Fig. 13 (b) shows liquid fraction change trend of shaping phase change material and composite phase change material in solidification process. From the figure, the composite phase change material melting speed is far greater than the shaping phase change material; when the liquid fraction is 0.5, the foam aluminum composite phase change wall with 13h, until the phase change material completely solidified, the liquid fraction reaches 0, with about 21h, about 4.5% less time, improve the efficiency of heat transfer; thermal conductivity type of phase change material, and the heat is from the outer wall to the south wall in the direction of diffusion layer and more slowly, so in the exothermic stage of 8~24h, the liquefaction rate of shaped phase change material is higher than the composite phase change material.



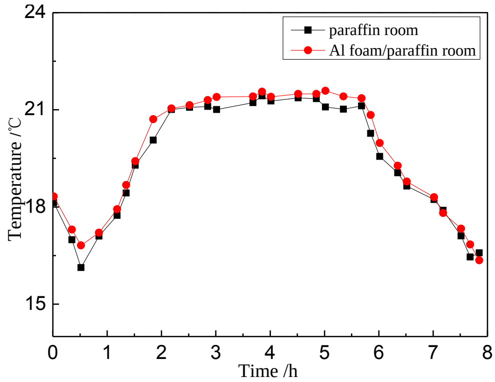
(a)



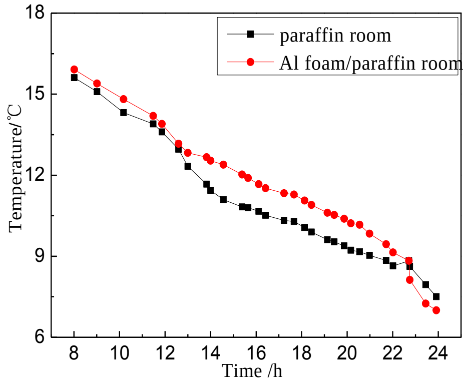
(b)

Fig. 13 The liquid rate curves of composite/mixed phase change materials in melting and solidification

Fig. 14 (a) and (b) are the change of the temperature of the D point at the center of the room with the addition of foamed aluminum during the melting and solidification process. From the figure a, the temperature of the exterior environment is lower than that of the indoor temperature in the south wall heat storage period, but the poorer the heat transfer performance of the south wall, the smaller the heat flow through the wall to the interior, lost to the external environment by the room through the building envelope heat cannot be added, therefore, the indoor temperature has been reduced to a certain extent; The lower the thermal conductivity, the smaller the heat flow to the room, the indoor temperature decreased relatively fast, so the temperature of shaped phase change solar house decreased faster than the compound phase change solar house; the temperature of indoor air increases with the increase of thermal conductivity. Figure b is the variation of the temperature with the time of the D point at the center of the shaped phase change solar house and the compound phase change solar house during the heat release process. According to the diagram, because of the poor heat transfer performance of the shaped phase change material, the room temperature drops rapidly than the composite phase change room. But since there is latent heat of phase change material, can be released as the heat load of the room, the temperature drop at the end stage heat is not severe; but 21h to 24h hours, the temperature of composite phase change material indoor decreased rapidly, which is mainly due to the composite phase change material has good heat transfer performance, at about 21h have all been solidified, all latent heat stored has been released, only through the release of sensible heat to compensate for the loss of heat flow outside the room, so the room quickly cool.



(a)



(b)

Fig.14 (a) The temperature variations of point D in melting, (b) the temperature variations of point D in melting and solidification

4. Conclusions

In order to improve the thermal performance of paraffin phase-change material, with aluminum foam as porous matrix, melting point close to the optimal temperature of mixed paraffin, preparation of aluminum foam / paraffin composite phase-change material, and the heat release characteristics of composite phase change materials and building materials were put into the wall under winter conditions from two aspects of numerical calculation and experiment, and the influence of the channel and the room temperature. The results obtained by the two methods are compared and analyzed, and the following conclusions are obtained:

(1) In the south wall of the solar house, a phase change heat storage material with a melting point close to the optimum temperature can maintain the indoor temperature balance well. Phase change materials have certain thermal storage and thermal resistance. During the day, they can not only prevent excess heat from being introduced into the room, but also prevent indoor temperature loss, so that the room has been maintained in a comfortable temperature range. The temperature of the outer wall of the south wall appears to be delayed due to the thermal storage capacity of the phase change heat storage wall, and the air temperature in the solar channel gradually increases with the height.

(2) FLUENT simulations were used for analysis. In the thermal storage stage, the melting rate of the foam aluminum / paraffin composite phase change wall is much higher than that of the paraffin shape, and the temperature increases gradually along the height direction in the Trombe wall structure; In the exothermic stage, the liquefaction rate of paraffin shaped phase change material is higher than the other two groups, the smaller the coefficient of thermal conductivity is, the more obvious the room temperature drops, improving the thermal conductivity of material is beneficial to wall heat preservation.

(3)The experimental results are compared with the numerical results: the delay time in the simulation process is longer than the experimental time, and it can not be completely adiabatic under the experimental conditions, the experimental and simulation results have some deviations, and the experimental values are low, but the maximum is not more than 18%, in a certain range of error, to meet the actual requirements.

References

[1] Zhou Yan, Li Qingling, Li Jiehao, Liu Xiaohui. Journal of Engineering Thermophysics, **31**(3), 465 (2010).

[2] Code for design of heating, ventilation and air conditioning for civil buildings: GB50736-2012[M]. China Building Industry Press, 2012.

[3] H. C. Min, C. P. Jin, [J]. Energies, **10**(2), 195 (2017).

[4] Hua Weisan, Zhang Xuelai, Luo Xiaoxue, Liu Yufei, Wang Wei. Acta Energiae Solaris Sinica, **38**(6), (2017).

[5] X. Zhang, R. Wen, Z. Huang, et al. Enhancement of thermal conductivity by the introduction of carbon nanotubes as a filler in paraffin/expanded perlite form-stable phase-change materials[J]. Energy & Buildings, 2017, 149.

[6] N. Şahan, H. Paksoy Investigating thermal properties of using nano-tubular ZnO powder in paraffin as phase change material composite for thermal energy storage[J]. Composites Part B Engineering, 2017.

[7] H. Zou, S. Wu, J. S hen. Chemical Reviews, **108** (9), 3893 (2008).

[8] Zhang Jinhui. Study on thermal properties of paraffin wax and its composite phase change materials [D]. Qingdao University of Science & Technology, 2014.

[9] Li Zhengrong. Analysis on Heat-transfer of Energy-storing Building Construction.

Journal of Tongji university **29**(3), 338 (2001).
[10] N. Soares, J. J .Costa, A. R. Gaspar, et al. Energy & Buildings, **59,** 82 (2013).
[11] A. Pasupathy, R. Velraj, Energy & Buildings, **40**(3), 193 (2008).
[12] A. Chakraborty. International journal of solids and structures **48**, 71 (2011).
[13] Thermal design code for civil building. GB50176-1993[M].