HEAT TRANSFER PERFORMANCE OF PHASE CHANGE ENERGY STORAGE BUILDING MATERIALS AND ITS APPLICATION IN ENERGY EFFICIENT BUILDINGS

by

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The author proposes a phase change heat storage component combined with the light wall interior to improve the heat storage performance. Numerical modelling of the composite wall was performed using the finite element program COMSOL connected to Multiphysics simulation, and its accuracy was verified. In order to optimize the use of phase change data and the benefit of phase change temperature, the phase change of the heating device was carried out, and the difference in the development efficiency of the thermal storage performance of the two types of light walls was obtained from the ribs in the thermal phase phase exchanger compared. The results show that the long and thin fins adjust the temperature and flow field changes of the paraffin to the corresponding fin gap and improve the heat transfer rate, 44.8 and 26.3, respectively, the aerated concrete combined wall heat storage and heat release time, added short ribs known need, and the connected wall delay time is not affected by external heat. The mature thermal insulation and thermal insulation time of the polystyrene board composite wall were shortened by 20.8 and 52.9, respectively. Ribs are able to improve heating efficiency and retain heat in the broken walls of polystyrene panels. The author's research can provide a rationale for the design and use of phase change thermal storage.

Key words: *variable heat storage components, heat transfer enhancement, numerical simulation, thermal storage performance*

Introduction

The energy efficiency level of new urban buildings in 2020 will be increased by 20% compared to 2015, at the same time, higher requirements are put forward for the energy-saving standards of building envelope structures, requiring the energy-saving standards of key parts of the envelope structure to reach international advanced levels [1]. The main goal of building energy-saving work has always been to pursue energy efficiency improvement, and a series of energy-saving design standards for building envelope structures have been issued. The energy-saving standards have been increased from 30-65%, and even some cities have proposed an energy-saving target of 57%. The requirements for the performance of envelope structures and building materials are also increasing.

The insulation performance of the building envelope has a positive effect on the energy consumption of the building. From the definition of domestic energy consumption, the general definition of domestic energy consumption generally includes the production and transportation of materials and equipment during construction, maintenance, utilities, household appli-

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ances. Low building energy consumption only includes the energy use of building operations, *i.e.* energy used for daily use such as heating, cooling, lighting, cooking, household appliances, and electricity used to improve indoor heating [2]. It consumes about 80% of electricity in the environment, money, about 80 energy saving works. The heat transfer characteristics of the building structure determine its thermal insulation properties, including insulation, transparency, and resistance to external temperatures, which have a significant impact on indoor comfort and energy efficiency. According to China's Atlas of Energy-Efficient Design and Building Envelope Design, energy-saving energy-saving designs are often added to the insulation layer in the grass envelope design. Insulating materials are usually porous materials such as rock wool, slag wool, aerated stone blocks, or organic materials such as extruded polystyrene board and polyurethane [3]. Composite material boards such as polystyrene are preferred density and low thermal conductivity – tab sis that effectively reduces the heat transfer coefficient of the envelope has little effect on improving thermal storage performance.

Literature review

China is a populous country. Although its total resources are large, its energy stock is insufficient, and the per capita share of energy ownership is only 40% of the global population. This indicates that the per capita resources are small, and the energy situation is not optimistic. According to relevant survey data: the energy used for building heating in northern China accounts for up to 20% of the total energy consumption, and the amount of CO_2 generated during the heating phase is greater than in other stages, moreover, the number of urban residents in China using air conditioning has increased from 25.12% in 1998 to 40.21% in 2010. In 2010, building energy consumption reached 32.6% of the total social energy consumption in China. It can be seen that the overall level of building energy consumption is relatively high. The relevant data indicates that China's energy consumption level is at a relatively high level globally. With the progress of China's economy, the construction industry in China will rapidly expand in the coming periods. By 2020, within the expected public building space, the average floor area for urban residents will be 46 m^2, and the proportion of people living in rural areas will also reach as high as 40 m^2. With the improvement of people's quality of life, they have increased their attention the level of living comfort. According to relevant statistical data, the overall energy consumption in society is increasing at a rate of 1% per year. As of 2010, this proportion was as high as 33%. By 2020, China's construction energy consumption will account for 50% of the total social energy consumption, construction area will account for 49% of the total arable land area, and construction pollutants will account for over 28% of the total pollution emissions. In the future, we will pay a huge price for energy consumption and waste today. In addition, the influence of natural-convection of PCM liquid phase on the heat transfer process must be taken into account for the macro encapsulated phase change heat storage components, and the geometric parameters of fins on the heat storage/release rate of the phase change envelope and the thermal performance under periodic heat action still need to be further clarified. However, natural-convection in liquid-phase transfer data is often neglected in current experimental studies, and there are few studies that combine macrovolume with improved heat transfer models. Kishore *et al.* [4] conventional thermal insulation (with thermal resistance) limits the use of PCM, which is believed to limit the energy efficiency of PCM construction more or less. Yasiri and Szabo [5] comprehensive review of alkanes and their uses and applications, with special emphasis on their potential for developing paper applications. In addition, the general characteristics and expectations of PPCM are clarified and evaluated. Liu *et al.* [6] reviewed the latest VBGHE developments, including improvements in heat transfer, drilling, integration of thermal energy storage, and new design tools. When the ground has a high thermal conductivity, the design of the drill and the development of the necessary materials are more important.

Based on the aforementioned analysis, in view of the heat transfer process of the composite wall with phase change heat storage components and the liquid phase natural-convection of PCM, the author uses the finite element software COMSOL coupled with multiphysics simulation establish the model of phase change heat storage components applied to the interior surface of the lightweight wall in summer. By simulating and optimizing the optimal rib parameters of phase change heat storage components, the differences in the thermal storage performance of two types of lightweight walls improved by ribs in phase change heat storage components are compared, in order to provide reference for the design and application of phase change enclosure structures.

Heat transfer model of composite walls with phase change thermal storage components

Simulation methods

The flow is 2-D, transient laminar flow movement, and the density change meets the Boussinesq approximation assumption. Based on the previous assumptions, the unsteady heat transfer control equation for composite walls:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \times (-k \nabla T) + \rho C_p u \nabla T = 0 \tag{1}$$

where u [ms^{-1}] is the velocity field vector.

Define the liquid fraction of the phase transition process through temperature changes:

$$\theta = \begin{cases} 0 & T < T_m - \dfrac{\mathrm{d}T}{2} \\ \dfrac{T - T_m + \dfrac{\mathrm{d}T}{2}}{\mathrm{d}T} & T_m - \dfrac{\mathrm{d}T}{2} < T < T_m + \dfrac{\mathrm{d}T}{2} \\ 1 & T > T_m + \dfrac{\mathrm{d}T}{2} \end{cases} \tag{2}$$

where T_m [°C] is the melting temperature and ΔT [°C] – the phase transition temperature radius.

The density, heat capacity, volume fraction, and are defined based on the liquid fraction, and are represented by eqs. (3)-(6), respectively:

$$\rho = \theta \rho_{\text{phase1}} + (1-\theta)\rho_{\text{phase2}} \tag{3}$$

$$C_p = \left(\frac{1}{\rho}\theta \rho_{\text{phase1}} C_{p,\text{phase1}} + (1-\theta)\rho_{\text{phase2}} C_{\text{p,phase2}}\right) + L\frac{\partial a_m}{\partial T} \tag{4}$$

$$a_m = \frac{1}{2}\frac{(1-\theta)\rho_{\text{phase2}} - \theta\rho_{\text{phase1}}}{\theta\rho_{\text{phase1}} + (1-\theta)\rho_{\text{phase2}}} \tag{5}$$

$$k = \theta k_{\text{phase1}} + (1-\theta) k_{\text{phase2}} \tag{6}$$

where ρ_{phase1}, $\rho_{\text{phase 2}}$ [kgm^{-3}] are the solid and liquid phase densities of PCM and k_{phase1}, k_{phase2} [Wm^{-1}°C^{-1}] – the average thermal conductivity, solid and liquid thermal conductivity of paraffin.

The fluid motion control equation of liquid paraffin is described:

$$\rho\frac{\partial u}{\partial t}+\rho(u\nabla)u=\nabla\times[-pI+\mu\left(\nabla u+(\nabla u)^T-\frac{2}{3}\mu(\nabla u)I\right]+F+\rho\mathrm{g} \tag{7}$$

where ρ [kgm^{-3}] is the liquid phase density, P – the fluid pressure, and F – the volumetric force vector, consisting of two parts, $F = F_a + F_b$. The dynamic viscosity of the liquid fraction [7]:

$$F_a=-A(T)u \tag{8}$$

$$A(T)=\frac{C(1-\theta)^2}{\theta^3+\varepsilon} \tag{9}$$

where $A(T)$ is the fluid power viscosity damping term, C and ε are the random number, $C = 10^5$, $\varepsilon = 10^{-3}$, according to Boussinesq's approximate definition of buoyancy term AA:

$$F_b=\mathrm{g}\rho_{\mathrm{phase2}}a_m(T-T_m) \tag{10}$$

In the equation, the meanings of other parameters are the same as before.

Boundary conditions

– *Boundary conditions of the external surface of the wall*: The heat transfer process on the external surface of the composite wall is expressed:

$$-k\frac{\partial T_2}{\partial t}=h_{\mathrm{out}}(T_{\mathrm{se}}-T_2)+aI(t)-\varepsilon\sigma\left(T_{\mathrm{se}}^4-T_2^4\right) \tag{11}$$

where T_{se} [°C] is the comprehensive outdoor air temperature, α – the solar radiation absorption coefficient, taken as 0.73, and I(t) [Wm^{-2}] – the solar Radiant intensity.

Outdoor air comprehensive temperature T_{se}:

$$T_{\mathrm{se}}=T_{\mathrm{out}}+\frac{aI}{h_{\mathrm{out}}}-T_{1_{\mathrm{r}}} \tag{12}$$

where aI/h_{out} [°C] is the equivalent temperature of solar radiation, T_{1_r} [°C] – the effective long-wave radiation temperature of the outer surface, taken as 1.80.

The GB 50176-2016 *Code for the Design of Civil Building Execution* provides the boundary conditions of the exterior surface of the enclosure structure on the typical day of the hottest month in summer, including the hourly temperature of outdoor air and the hourly value of solar radiation in each direction, in the benchmark conditions for the evaluation of exterior wall insulation design. The hourly value of outdoor air temperature in A is represented by the simple harmonic:

$$T_{\mathrm{out}}=31.98+3.5\cos\frac{\pi(t-13)}{12} \tag{13}$$

– Boundary conditions of the inner surface of the wall: The heat transfer process on the inner surface of the wall is expressed:

$$-k\frac{\partial T_2}{\partial t}=h_{\mathrm{in}}(T_2-T_i)-\varepsilon\sigma\left(T_2^4-T_i^4\right) \tag{14}$$

where T_i [°C] is the indoor air temperature, with an air conditioning condition of 26 °C, taken as 8.7 W/m^2°C, and other parameters have the same meanings as before.

– *Physical parameters of materials*: Two types of lightweight walls, aerated concrete and polystyrene board, are selected. The phase change heat storage components are filled with paraffin, and the components are encapsulated and the internal ribs are made of lightweight and well thermally conductive aluminum.

Model validation

Taking the heat storage process of phase change heat storage components as an example, four models with grid numbers of 8714, 13668, 21590, and 36138 were used for verification. Considering the calculation economy and simulation accuracy comprehensively, the grid number of 21590 is selected for simulation research [8].

The phase change heat storage component in the literature is used to combine with the solar PV panel on the exterior wall. The initial temperature and ambient temperature are 20 °C, the air convection heat transfer coefficient of the front and rear surfaces of the component are 10 W/m^2°C and 5 W/m^2°C, respectively, and the radiant heat flux of the solar photovoltaic panel surface is 1000 W/m^2. Compare the model results using the maximum relative error value and the calculation formulas are shown:

$$RME = \max\left(\left|\frac{x_{\text{sim}} - x_{\text{ref}}}{x_{\text{ref}}}\right| \times 100\%\right) \tag{15}$$

$$RAE = \text{average}\left(\left|\frac{x_{\text{sim}} - x_{\text{ref}}}{x_{\text{ref}}}\right| \times 100\%\right) \tag{16}$$

The maximum of the radiation surface and average temperature of PCM between the established model and the literature model are 4.58%, 0.51%, 1.67%, and 1.62%, respectively. This indicates that the model in this article is reasonable and reliable, and can be used for relevant simulation research.

Selection of optimal rib parameters for phase change heat storage components

When phase change heat storage components and composite lightweight walls are applied in summer, the heat transfer enhancement of PCM should not affect the insulation performance of the composite wall. The purpose of adding ribs inside the component is to reduce the heat transfer resistance of PCM, strengthen their response to environmental temperature changes, and thereby increase effective heat storage. Based on the aforementioned heat transfer enhancement approach, in order to ensure that outdoor thermal disturbances are not directly transmitted indoors through PCM, the fin length is smaller than the internal width of the component and distributed on one side of the indoor area. Different fin parameters will have different effects on the heat transfer process of phase change heat storage components. The more fins used, the better heat transfer effect cannot be achieved. The optimal fin structure should be selected based on comprehensive consideration of heat transfer efficiency, fin parameters, component weight, and cost. Convection and radiation heat transfer between the component and the indoor air contact surface are not considered.

The complete melting time of paraffin gradually decreases with increasing quantity for ribs of the same length and thickness. However, the increase in the number of ribs also reduces the spacing between the ribs, hindering the flow of liquid paraffin. Ribs with a spacing of 4 mm have a longer complete melting time of 4 minutes compared to 5 mm. For ribs with the same spacing and length, the complete melting time gradually decreases with the increase of rib length. Although increasing the thickness of fins with the same spacing and thickness can reduce the heat transfer resistance of paraffin, it also reduces the spacing between fins, resulting in a decrease in the convective heat transfer efficiency of liquid paraffin between fins. The complete melting time decreases with the decrease of fin thickness [9].

Comparing the heat transfer parts of the mixture heat transfer stage and the other fin alcohol of the heat storage process, the difference is small. The higher the temperature, the better the heat transfer heat storage. stage. According to the changes in heat transfer mechanism during the heat storage process, the heating law of PCM is divided into three-stages. Temperature allows the mixture to show the same three phases: the mature phase that requires heat release before the change phase, the latent heat transfer phase during the phase transition, and the mature liquid phase. is known to warm the phase after the phase transition:

– *Solid phase maturation consider the heat transfer stage*: In this stage, the heat transfer mechanism is mainly heat conduction. For the same amount of paraffin, the thermal conductivity of the fin determines the temperature change during this period. The surface and ribs of the mixture are first heated and then turned into paraffin, so the temperature difference shows an increase and then a decrease change. Comparisons in fig. 2 show that length has the greatest effect on temperature changes during this period, followed by fish thickness and fish species. This indicates that the longer the fish, the faster the temperature changes during this period.
– *Latent heat storage stage*: The heat exchanger of this stage is a combination of liquid paraffin heating and natural-convection heat transfer. As the amount of liquid paraffin increases, the natural-convection heat changes and the temperature difference increases. Among them, the infinite temperature difference is increased, which, due to the natural-convection of liquid paraffin, causes the thermal unevenness of the component air at this level, as the paraffin material is placed at the bottom of the material. Through comparison, it can be seen that the length of the ribs has the most significant impact on the temperature difference during this stage, followed by the number of ribs, and the thickness has the smallest impact. As the length of the rib increases, the temperature difference continuously decreases and tends to stabilize. This shows that the fins with sufficient length can effectively suppress the adverse effects of liquid paraffin natural-convection, improve the uneven heating of components, and enhance the heat transfer rate.
– *Liquid sensible heat storage stage after phase change*: The heat transfer mechanism of this stage is mainly the natural-convection heat transfer of liquid paraffin. From the comparison, it can be seen that the thickness of the ribs has the most significant impact on the temperature difference during this stage, followed by the quantity and the length. This phenomenon is consistent with the change in complete melting time. In fig. 1, the temperature difference with

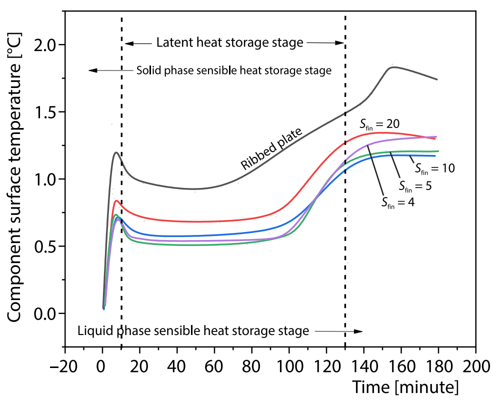

Figure 1. Effect of the number of ribs on the temperature difference

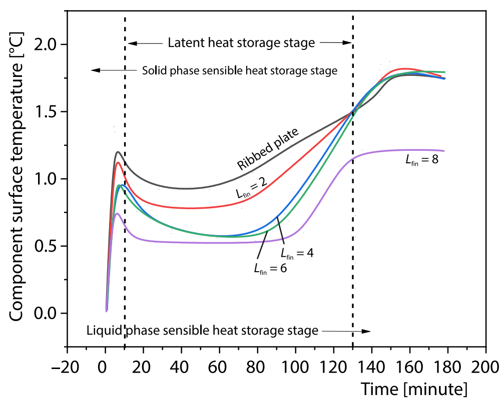

Figure 2. Effect of the rib plate length on the temperature difference

a rib spacing of 4 mm is higher than 5 mm, while in fig. 3, the temperature difference increases with the increase of rib thickness. This indicates that, if the distance between ribs is too small, it will hinder the flow of paraffin and reduce the heat transfer rate at this stage. From this, we obtain S_{fin}= 5 mm, L_{fin}= 8 mm, and T_{fin}= 0.2 mm is the optimal fin parameter for phase change heat storage components.

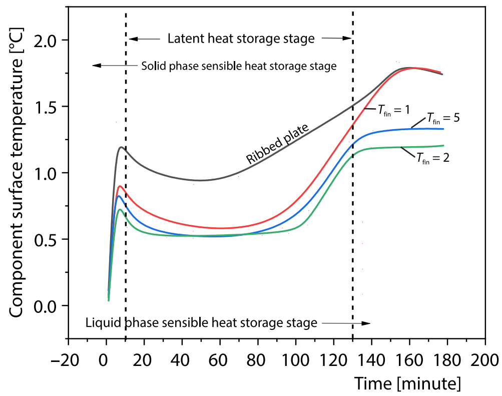

Figure 3. Effect of the rib plate thickness on the temperature difference

Experimental results and analysis

Phase change thermal storage components can improve the thermal storage performance of lightweight walls and enhance their ability to resist outdoor thermal disturbances. However, different lightweight walls exhibit different results in the attenuation and delay of outdoor harmonics. The author used the outdoor calculation parameters of a typical summer solar wall in a certain province for three cycles of cyclic simulation. The phase change heat storage components were, respectively combined with two types of lightweight walls, aerated concrete and polystyrene board, compare their differences in improving the heat storage performance of the two. Using finless phase change heat storage components and optimized finned phase change heat storage components to composite with two types of lightweight walls, the difference in heat storage performance between the two is improved by comparing the temperature of the inner surface of the composite wall and its attenuation multiple and delay time to outdoor thermal disturbance.

As shown in figs. 4 and 5, the amplitude of the internal surface temperature of the two types of lightweight walls significantly decreases under the action of phase change heat storage components. From the comparison of aerated concrete composite walls, it can be seen that the sensible heat storage and release time of non-ribbed components are 7.25 hours and 4.75 hours, respectively. The optimized components are 4 hours and 3.5 hours, respectively. The sensible heat storage and release time are shortened by 44.8% and 26.3% compared to non-ribbed components. From the comparison of polystyrene board composite walls, it can be seen that the sen-

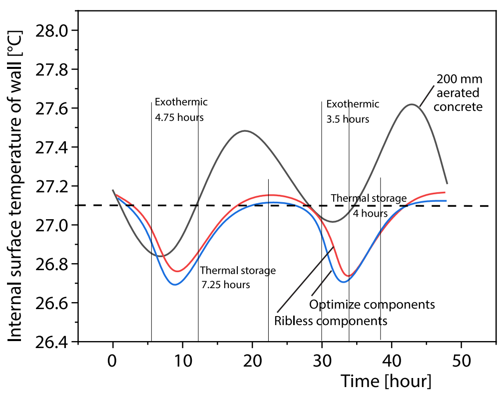

Figure 4. Effect of surface temperature in 200 mm aerated concrete light composite wall

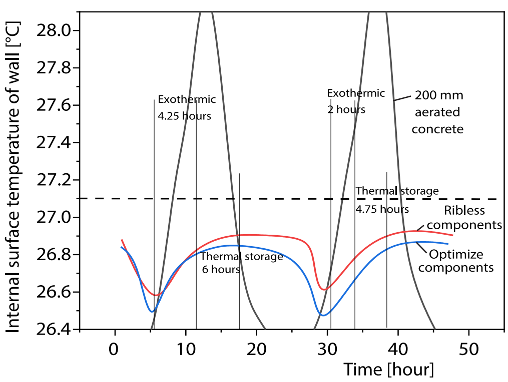

Figure 5. Effect of surface temperature inside the 50 mm polystyrene board lightweight composite wall

sible heat storage time and sensible heat release time of non-ribbed components are six hours and 4.25 hours, respectively, and the optimized component components are 4.75 hours and two hours, respectively. The addition of ribs shortened the sensible heat storage and release time of phase change heat storage components by 20.8% and 52.9%, respectively [10].

The temperature change on the inner surface of polystyrene boards with poor thermal inertness is relatively severe, causing the paraffin in the ribbed components to enter the next heat storage stage before fully releasing heat, leading to heat accumulation. Compared to the non-ribbed component, the optimized component reduces the minimum surface temperature inside the polystyrene board composite wall by 0.1 °C, and the occurrence time is about 1 hour earlier, which helps the paraffin to fully release heat, thereby increasing the effective heat storage of the paraffin.

From fig. 6, it can be seen that the phase change thermal storage component increases the attenuation multiple and delay time of outdoor harmonics by two types of lightweight walls. Under the same amount of paraffin wax, the use of optimized components increased the effective heat storage of paraffin wax, and the attenuation multiple delay time of the two types of lightweight composite walls was further increased. The attenuation coefficient of aerated concrete combined with the optimized component is 0.31 more than that of the non-ribbed component, and the delay time is 0.25 hours more than that of the non-ribbed component. The delay time of polystyrene board increased by 0.5 hours. From this, it can be seen that the ribs optimize the thermal storage/release performance of PCM without adversely affecting the insulation performance of the composite wall. The thermal storage capacity and effective heat storage of the polystyrene board composite wall with poor thermal inertia are better than those of the aerated concrete composite wall.

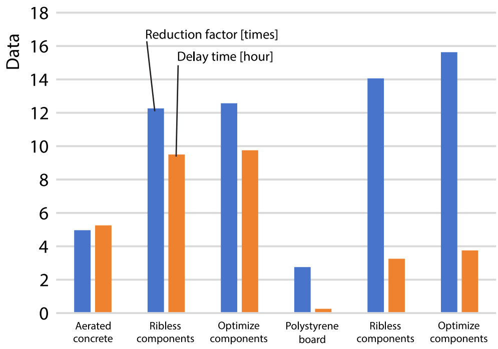

Figure 6. Comparison of attenuation multiple and delay time of the two light composite walls

Conclusion

In view of the poor thermal conductivity of paraffin, the author established a numerical model component applied to the inside of the lightweight wall through the multiphysics simulation coupled COMSOL finite element software. By selecting the optimal parameters of the internal ribs of the components and comparing their effects on improving the thermal storage performance of two types of lightweight walls, the conclusion is the length of ribs heat storage process of phase change heat storage components. Under appropriate rib spacing, long and thin ribs can enhance the synergy between the temperature field and flow field changes of paraffin, and enhance the heat transfer rate. The ribs in the phase change heat storage components shortened the sensible heat storage and release time of the aerated concrete composite wall by 44.8% and 26.3%, respectively, and the sensible heat storage and release time of the polystyrene board composite wall by 20.8% and 52.9%, respectively. Ribs not only increase the effective heat storage capacity of composite lightweight walls, but also enhance their heat storage and exchange capacity. The improvement effect of polystyrene board composite walls is better than that of aerated concrete composite walls. On the basis of macroscopic encapsulation of PCM, a finned structure with enhanced heat transfer is added to obtain phase change heat storage components that can be industrialized and applied in enclosure structures.

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