Application of Multivariate Composite Phase Change Materials in Building Exterior Renovation

Ting Huang*[a], Sicheng Jiang[b], Qi Luo[c]

[a]Yancheng Institute Of Technology, Yancheng 224000, China
[b]Yancheng Vocational Institute of Industry Technology, Yancheng 224005, China
[c]Jiangxi Normal University, Nanchang 330000, China
tinahwang1101@163.com

As an effective way to achieve a low consumption in the building energy efficiency field, the Phase Change Material (PCM) and Energy Storage (ES) technology have created a favourable condition for application of solar energy, wind energy and other low-cost clean energies in the heating system, A/C system. This paper probes into the simulation and application of composite PCMs in the exterior building enclosures with the physical model of houses. We therefore reach that the phase transition mortar board can effectively reduce the indoor temperature and stay the temperature fluctuation time when it is used for the outer insulation layer, such that it is sure to superior to the common mortar board.

1. Introduction

The ultimate purpose of the theoretical studies on PCMs at home and abroad is to popularize and apply the PCMs and its preparation technologies in various fields. PCMs have been widely used in the construction industry in diverse forms, for example, as the building envelopes such as the interior gypsum board, ceilings, exterior wall, and heat retaining panels, etc.; as a phase change heating floor for the HVAC system which make the indoor temperature distribution more uniform (Chaichan and Kazem, 2015, Giro-Paloma et al., 2015). This paper explores such application about the PCMs that a kind of form-stable PCM is prepared by the encapsulation after it is hybridized with the common lightweight construction material, in order to allow it play a temperature control effect on the roof structure, while it also has been proven to be effective in thermal insulation (Borderon et al., 2015, Hossain et al., 2015). For this purpose, the physical model of housing structure and the 3D theoretical simulation model are established to reveal the effect of PCMS on the indoor temperature fluctuation in the roof structure after and before it is mixed into the common materials. The paper also describes the simulation of its transient heat transfer process by ANSYS software (Solomon et al., 2015, Ramakrishnan et al., 2015).

2. Housing model design

To expose the effect of phase change energy storage mortar board as the roof structure on the indoor temperature of the house, this experiment is conducted using the wood house model 450mmX300mmX350mm with open roof where the phase change energy storage mortar board 420mmX300mmX30mm and heat insulation panel are allowed for placements. Its exterior skeleton is shown in Figure 1. It is discovered by the extensive studies that on the premise of the equivalent thickness, the wood structure is obviously superior to other construction materials in terms of the insulation, energy efficiency, namely, its thermal insulation is 3 times higher than that of the solid brick wall, 16 times higher than that of the standard concrete, and 400 times higher than that of the steels (Akeiber et al., 2016). This experiment, therefore, adopts the wood structure to effectively improve the heat insulation property of house. XPS (Extruded Polystyrene Board) with 3cm thickness is lined in the interior wall of house, which has been widely applied in wall insulation, steel roof and surface concrete roof insulations with thermal conductivity far lower than other insulation materials. It also features dense closed-pore structure, low water absorption, good anti-

permeability performance. On this basis, the model allows for this design to restrain the impact of external factors on the interior heat transfer of house (Asbik et al., 2016, Rao et al., 2016).

Figure 1: Appearance of housing model

Figure 2: Interior wall of housing model

3. Analysis of energy efficiency of phase change roof

In accordance with the preparation method of the phase change mortar in the pre-experiment, the common vitrified microbead mortar insulation board and the paraffin / vitrified microbead phase change energy storage mortar board, 420mm*300mm*30mm, are prepared respectively as the exterior insulation layer and the ceiling layer of roof structure (Fukahori et al., 2016,), along with one XPS board with the same size and thickness as a roof insulation waterproof material (Samim et al., 2016, Seddegh et al., 2016).

The phase change mortar board is used as the exterior insulation layer attached to the XPS, and the common vitrified microbead mortar insulation board as the blank control to simulate the roof structure. The house model is placed in a refrigerator at a temperature below 10°C until the internal temperature of the house model drops to 10°C or so, and then move it into an incubator at 40°C. Thermocouple is used to measure the temperatures at the points 1 (the hollow area inside the house model), 2 (side wall in the house model), 3 (lower XPS board), 4 (upper XPS board and mortar sandwich), observe the temperature gradient on each part, and record it once every 10min.

It takes 40min for the common mortar plate to heat up from 20.0°C to 29. 7°C, the indoor temperature in the house model gets to 38.5°C after 4h. The phase change mortar plate is used for the exterior insulation layer, it will take 60min when the internal temperature of the house model increases from 20.1°C to 29.6°C, about 1.5 times than the common mortar plate. After 4h, the internal temperature of the house model reaches 36.1°C, decreased by 1.6 °C when compared with common mortar plate used for exterior insultation material. In the light of the above fact, it is certain that the phase change energy storage mortar plate can prevent the heat from being transferred to the interior of the model by means of its own phase change latent heat and heat absorption properties. The heat it absorbs can effectively retard the indoor temp rise amplitude. Figures 3-6 represent the temperatures of points 1, 2, 3, and 4 when the phase change and common mortar plates are used as the exterior insultation lays of roof surface, respectively.
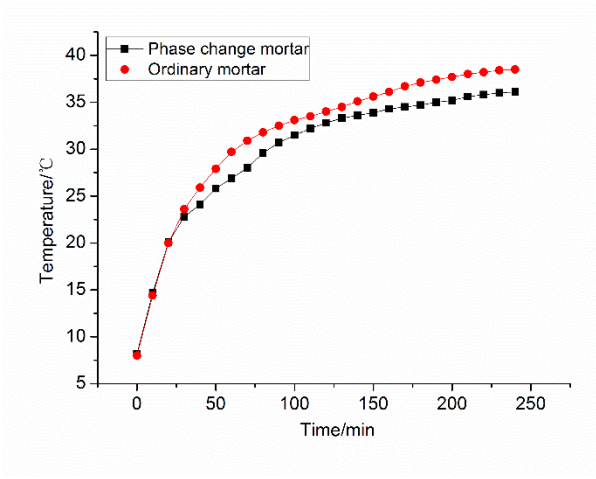
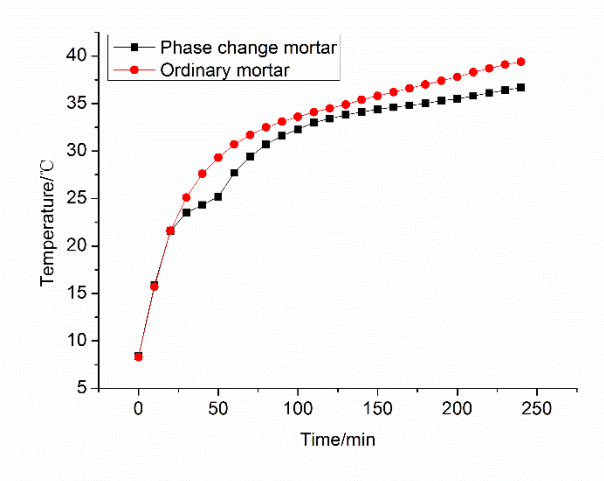*Figure 3: Temperature change of the hollow area inside the house model*

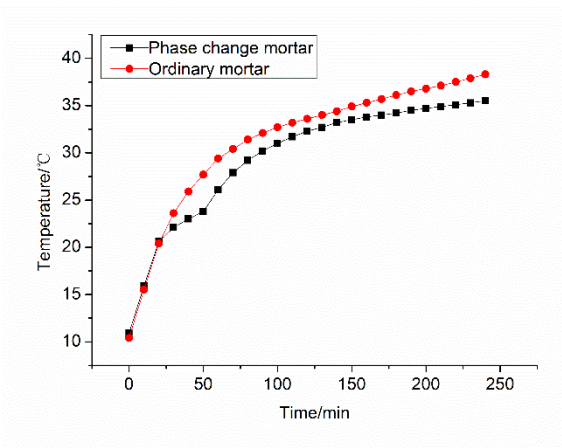*Figure 4: Temperature change of side wall in the house model*

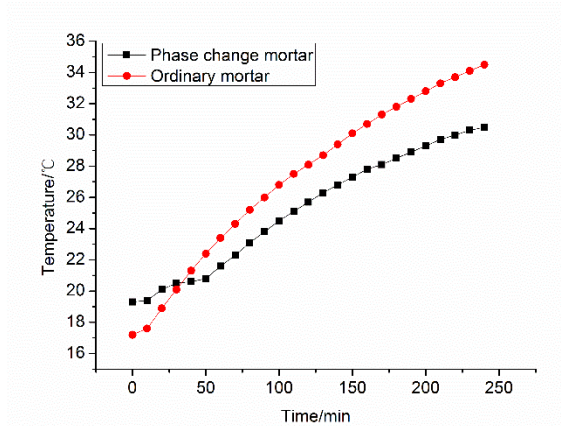
Figure 5: Temperature change of lower XPS board

Figure 6: Temperature change of upper XPS board and mortar sandwich

As shown in Fig. 3, it is obvious that, in relation to the common mortar plate, the indoor temperature fluctuation in the roof exterior-insulation layer added with PCMs is lower, and the indoor temperature, the side wall temperature and the behaviors under and above XPS are all less. The results show that the PCM additive can absorb external heat, significantly improve the thermal storage capacity of the roof structure, and reduce the indoor temperature fluctuation, so that a good control effect is overwhelming.

4. Simulation Analysis of Heat Transfer Based on ANSYS

ANSYS, a finite element analysis software, as a well-known commercial computer software, is widely used in many fields such as energy sources, chemical industry, building materials, metallurgy, etc. The software consists of three modules, i.e. the front-end processing, the analysis and computation module and the back-end processing. The front-end processing module provides us with a very powerful solid modeler and meshing tool which allows users to easily build a finite element model. Analysis and computation module can perform an analysis technology on the structural, hydrodynamics, thermal power, piezoelectricity, etc., to simulate the interaction of a variety of physical medium with the optimization analysis function. The back-end processing module can display the computed results graphically, or output them in graphs or curves. One of the most powerful features of this software in thermal analysis is to analyze complex phase change problems that many numerical analysis software fail to solve. It is required to fully consider the process of latent heat absorption and sublimation in the analysis of transient thermal transformation of the phase transition process. ANSYS can approximate its latent heat by defining material properties.

The temperature change test results of each part in the physical model are considered to choose the phase change mortar plate as the ceiling layer for simulating and analyzing the heat transfer characteristics. The concrete simulation procedure is given as follows: first, the 3D physical model for the above-mentioned housing structure is established by Solidworks. The blue coating on the roof structure represents XPSs, and the gray coating represents phase change mortar plate. Then, the 3D physical model is imported into the ANSYS Workbench by using the data interface to the software. A finite element model is also built for the physical house model. In the modeling process, the model must be streamlined in a reasonable way, such as remove the chamfer, orifice, and non-load systems, which not only improve the work efficiency, but also ensure the accuracy of the analytical results.

Set the analysis type: structural and thermal performance analysis.

Define the material properties: The thermal conductivity of the PC ES mortar plate is 0.3372W/m·K; the specific hear capacity is 1.04X10J/Kg; the density is 1460Kg/m3; the thickness 30mm; the thermal conductivity of XPS is 0.0300W/m•K; the specific hear capacity is 1.79X103J/Kg; the density is 35Kg/m3; the thickness 30mm;

Contact mode: the built-in nonlinear contact modal analysis solver NLMA in Workbench is used for solution.

Meshing: When using the free meshing function of ANSYS Workbench, the 3D physical model system generates 12,663 nodes and 38,754 units.

Apply the boundary conditions: set the initial temperature to 40 ° C, apply it to the upper surface of the model and only consider the effect of temperature on the environment in the model, ignore the radiative heat transfer and convective heat transfer.

Solution: The output results of the 3D model temperature and heat distribution are shown in Figure 7 and 8.
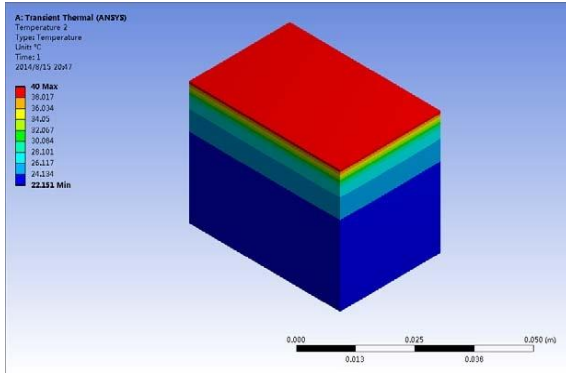
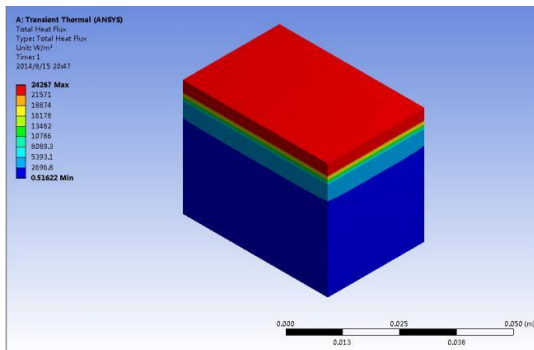*Figure 7: Temperature distribution in the 3D model*

Figure 8: Heat distribution in the 3D model

As can be seen from Fig. 4, when applying 40 °C to the red area on the upper surface of the model, i.e. the upper surface of the XPS, the transient heat transfer temperatures are in turn 38.02 °C, 36.03 °C, 34.05 °C, 32.07 °C, 30.08 °C, 28.10 °C, 26.12 °C, 24.13 °C, 22.15 °C from the upper surface of model to the bottom surface. XPS enables the heat insulation to make the temperature drop to about 300°C. The phase change mortar plate in turn stores the heat as the phase change latent energy, and further reduces the temperature. The temperature in dark blue area, i.e. the indoor temperature, is only 22.15 °C, which shows to be consistent with data measured in the actual house model as established. So effective can the phase change mortar plate placed in the ceiling layer be to control the indoor temperature.

As shown in Fig. 5, the total heat flow of all parts of 3D model is calculated when applying 40 °C to it, we can see that the heat flow does not fall substantially through the XPS plate, the red area, only from 24267W/m2 down to 21571 W/m2. After transferring to the phase change mortar layer, i.e. light blue area, the heat flow is significantly reduced to between 2696.85393.1W/m2, which implies that the phase change mortar plate absorbs a lot of heat, so that the internal phase change reaction occurs to convert the heat into latent energy.

5. Conclusion

A well-established physical house model can effectively simulate the application of the phase change material in the roof structure. When the phase change mortar plate is used for the exterior insulation layer, it takes 60 min when the internal temperature of the house model increases from 20.1 °C to 29. 6 °C, about 1.5 times than the common mortar plate. After 4h, the internal temperature of the house model gets to 36.1 °C, and 2.4 °C lower than that of common mortar board. In the light of the above fact, it is certain that the phase change energy storage mortar plate can prevent the heat from being transferred to the interior of the model by means of its own phase change latent heat and heat absorption properties. The heat it absorbs can effectively retard the indoor temp rise amplitude.

156

(2) Jiangsu Provincial Department of housing and urban rural development science and technology plan project: solar energy combined with phase change energy storage technology in existing residential building energy saving Transformation Research (2016ZD55).
(3) Application of phase change wall in energy saving renovation of existing buildings in Northern Jiangsu Province -- innovative training program for Provincial College Students (ycgy2017006).
(4) Science and technology program of Jiangsu Provincial Department of housing and urban rural development: performance of recycled aggregate eco green pervious concrete (2016ZD43).

Reference

Akeiber H., Nejat P., Majid M.Z.A., Wahid M.A., Jomehzadeh, F., Famileh, I.Z, et al., 2016, A review on phase change material (pcm) for sustainable passive cooling in building envelopes, Renewable & Sustainable Energy Reviews, 60, 1470-1497, DOI: 10.1016/j.rser.2016.03.036

Asbik M., Ansari O., Bah A., 2016, Exergy analysis of solar desalination still combined with heat storage system using phase change material (PCM), Desalination, 381, 26-37, DOI: 10.1016/j.desal.2015.11.031

Borderon J., Virgone J., Cantin R., 2015, Modeling and simulation of a phase change material system for improving summer comfort in domestic residence, Applied Energy, 140, 288-296, DOI: 10.1016/j.apenergy.2014.11.062

Chaichan M.T., Kazem, H.A., 2015, Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (pcm), Case Studies in Thermal Engineering, 5(C), 151-159, DOI: 10.1016/j.csite.2015.03.009

Fukahori R., Nomura T., Zhu, C., Sheng N., Okinaka N., Akiyama, T., 2016, Thermal analysis of al–si alloys as high-temperature phase-change material and their corrosion properties with ceramic materials, Applied Energy, 163, 1-8, DOI: 10.1016/j.apenergy.2015.10.164

Giro-Paloma J., Konuklu Y., Fernández A.I., 2015, Preparation and exhaustive characterization of paraffin or palmitic acid microcapsules as novel phase change material, Solar Energy, 112(112), 300-309, DOI: 10.1016/j.solener.2014.12.008

Hossain R., Mahmud S., Dutta A., 2015, Energy storage system based on nanoparticle-enhanced phase change material inside porous medium, International Journal of Thermal Sciences, 91, 49-58, DOI: 10.1016/j.ijthermalsci.2014.12.023

Ramakrishnan S., Sanjayan J., Wang X., et al., 2015, A novel paraffin/expanded perlite composite phase change material for prevention of PCM leakage in cementitious composites, Applied Energy, 157, 85-94, DOI: 10.1016/j.apenergy.2015.08.019

Rao Z, Wang Q, Huang C., 2016, Investigation of the thermal performance of phase change material/mini-channel coupled battery thermal management system, Applied Energy, 164, 659-669, DOI: 10.1016/j.apenergy.2015.12.021

Samimi F., Babapoor A., Azizi M., Karimi G., 2016, Thermal management analysis of a li-ion battery cell using phase change material loaded with carbon fibers, Energy, 96, 355-371, DOI: 10.1016/j.energy.2015.12.064

Seddegh S, Wang X, Henderson A.D., 2016, A comparative study of thermal behaviour of a horizontal and vertical shell-and-tube energy storage using phase change materials, Applied Thermal Engineering, 93, 348-358, DOI: 10.1016/j.applthermaleng.2015.09.107

Solomon L., Elmozughi A.F., Oztekin A., et al., 2015, Effect of internal void placement on the heat transfer performance – Encapsulated phase change material for energy storage, Renewable Energy, 78, 438-447, DOI: 10.1016/j.renene.2015.01.035