Energy Saving Simulation of Phase Change Materials in the Enclosure Structure of Archives Warehouse in Different Climatic Regions

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Abstract: Different climates in different regions have an important influence on the latent heat performance of PCMs, especially outdoor temperature and solar irradiance. This paper describes the addition of PCMs outside the archives warehouse in Guangzhou and Lhasa, and the temperature change and energy conservation of the exterior enclosure of the warehouse in summer and winter. In typical summer days in Guangzhou, PCMs with a phase change temperature of 30℃ should be added to reduce the indoor cooling load by 23.91%. In typical winter days in Lhasa, PCMs with a phase change temperature of 8℃ should be added, which can reduce the indoor heat load by 17.28%.

1 Prologue

Phase change energy storage material is a new type of energy saving, environmental protection and recyclable material. With the awareness of practicing the five development concepts of innovation, coordination, green, openness and sharing, People pay more and more attention to the requirement of green energy saving. Archives are important places for keeping and storing archives, so it is necessary to carry out the adaptability study of phase change energy storage materials in the archives in order to save energy.

Many scholars have studied PCM. *Onishi et al*. studied the storage system performance of the Trombe wall combined with electric heating at night in the passive solar room, and used PCMs in the Trombe wall to reduce the surface temperature of the outer wall and improve the thermal efficiency[1].BASF Company of Germany adopts microencapsulation technology to encapsulate paraffin wax in capsules with a diameter of about 20 microns, and then mix it with plaster to prepare a phase change energy storage mortar for interior walls, which contains 15%~25% microcapsules, that is, 750~1500g microcapsules per square meter of wall surface. As a material for indoor thermal insulation in winter and cooling in summer, this mortar can reduce indoor temperature fluctuation.

In China, *Zhou Jianmin* [2-3] of Tongji University and *Ma Fangmei* [4] of Huazhong University of Science and Technology conducted in-depth research on composite PCMs, including preparation methods, thermophysical properties and service life.Yang *Yushan et al*.[5] added activated carbon energy storage aggregate prepared with butyl stearate as PCMs to concrete to replace part of pebbles and graphite to replace part of river sand, and prepared phase change concrete by the method of preparing ordinary concrete. The results show that the addition of activated carbon energy storage aggregate makes a large number of PCMs stored in concrete, making the specific heat capacity of phase change concrete much higher than that of ordinary concrete.

According to the division of climate regions in China, Guangzhou is a hot summer and warm winter region, with the cooling energy consumption mainly in summer throughout the year. Lhasa is mainly dominated by heating energy consumption. Therefore, when analyzing the adaptability of PCMs, the two regions should respectively consider the impact of main indoor load periods, air temperature and solar irradiance, and select the suitable phase change temperature of PCMs.

2 Load simulation study

2.1 Model design

Overall area of archive warehouse model is 10990.08 ㎡.The model is divided into 7 areas. The building model is shown in Fig. 1.

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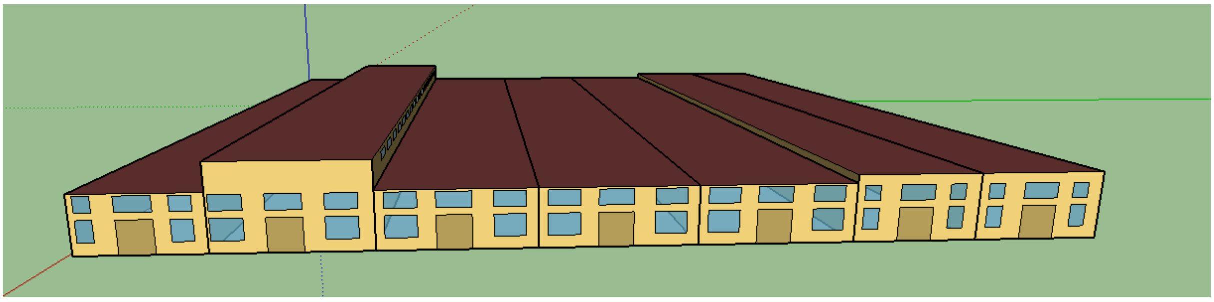

Fig. 1 Model diagram of archives

Based on references [6-9], in the model, the heat transfer coefficient of the outer door on the middle east wall is 0.03W/(㎡·K), the outer window's coefficient is 0.9W/(㎡· K), and PCM's enthalpy is 221KJ/Kg. Two models were studied and established in the simulation process (Figure 2).

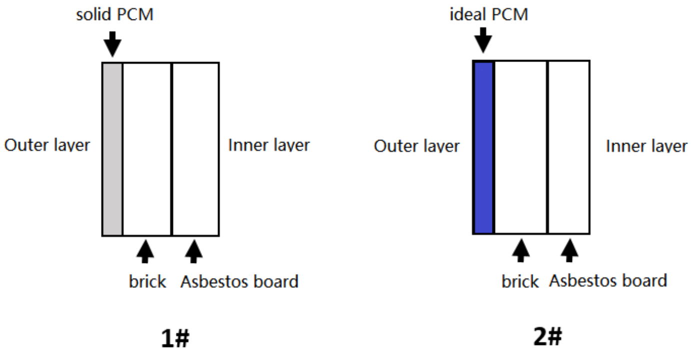

Fig. 2 Abridged general view of Two Models

As shown in the figure that two models have the same thermophysical characteristics. Take Guangzhou as an example, enthalpy change of PCMs in two models is shown in Fig. 3.

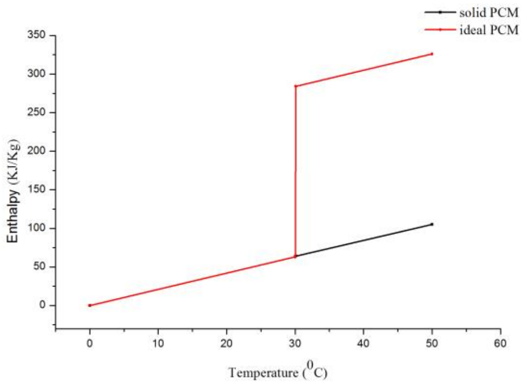

Fig. 3 Enthalpy-temperature curves of Two Models

As shown in Figure 3, the latent heat effect of PCMs can be seen more significantly. When the material temperature is 30℃, the enthalpy value suddenly increases, which means that the latent heat changes. According to the temperature requirements of *JGJ25-2010*, the air conditioning system of two models is set at 14~24 ℃.

2.2 Description of climatic conditions

This project mainly studies the application effect of phase-change walls in archives under different climatic conditions in China, so the analysis of climatic conditions is an important part. As the sunlight provides natural lighting for the building, the solar radiation shines on the building's outer enclosure and enters the room through the outer window, forming the heat of solar radiation. In winter, the solar radiation heats the indoor air, while in summer, it is required to block the solar radiation outside.

However, according to the previous thermal climate zoning, the inconsistency between the climate zoning and the administrative zoning has led to the unclear implementation of energy conservation standards for the buildings of the municipal administrative units including Duohe building climate zone, which has increased the cost of administrative management and reduced the operability and effectiveness of building energy conservation standards to a certain extent. Therefore, he proposed that the level of solar radiation should be taken into account when dividing climatic regions.

According to the division of climatic regions, different cities in different climatic regions are selected for comparison. The hot summer and warm winter regions in Guangzhou and the cold regions with high annual solar irradiance in Lhasa are selected for simulation analysis.

Annual average temperature in Guangzhou: 22.23℃, annual average radiation: 67.10W/m^2. Guangzhou has a subtropical marine monsoon climate. As it is located in a low latitude area and close to the South China Sea, it is affected by winter and summer monsoon alternately within a year, with climatic characteristics such as abundant light, warm heat and less cold, and abundant rainfall. Therefore, the archives in this area are mainly subject to indoor cooling load throughout the year.

The climate type of Guangzhou is subtropical monsoon climate, which is characterized by high temperature, large precipitation, sufficient sunshine, regular summer and short frost period. Guangzhou mainly focuses on cooling load, and July 21 is selected as a typical day for analysis. According to the analysis of meteorological parameters, there are two peaks of outdoor dry bulb temperature in typical days, the maximum temperature is 29.43℃ and 29.33℃ respectively, and the maximum solar irradiance can reach 378.275W/m^2. The trend of meteorological data is shown in Figure 4.

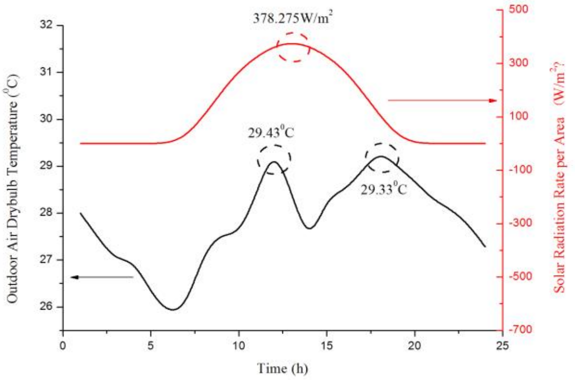

Fig. 4 Outdoor parameters in Guangzhou for July 21st

The annual average temperature in Lhasa is 8.30℃, and the annual average radiation is 232.48W/m^2. Lhasa is located in the Tibet Plateau. The climate of the Tibet Plateau is characterized by a large temperature difference between day and night throughout the year. The temperature is higher when the sun comes out in the daytime, hotter at noon, and lower when the sun goes down. Therefore, the annual indoor heat load of the archives in this area is higher than the indoor cooling load.

The annual sunshine time in Lhasa above 2800 hours [6]. The heat load in Lhasa is mainly in winter, and January 21 is selected as the typical day for analysis. According to the analysis of meteorological parameters, the maximum outdoor dry bulb temperature in typical days is 8.31℃, and the maximum solar irradiance is 34.5W/㎡. The trend of meteorological data is shown in Figure 5.

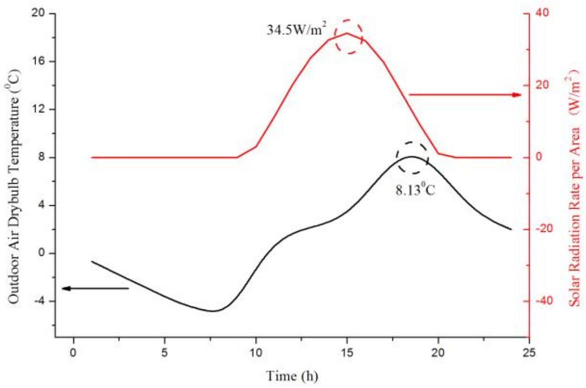

Fig. 5 Outdoor parameters in Lhasa for January 21st

3 Discussion on simulation results

3.1 Simulation analysis of typical weather in Guangzhou

The indoor load calculation formula is shown in Formula (1) [10].

$$\eta_a = \frac{Q_{1\#} - Q_{2\#}}{Q_{1\#}} \times 100\% \quad (1)$$

As shown in the formula, η_a is annual energy saving rate,$Q_{1\#}$ and $Q_{2\#}$ is annual energy consumption of two models , KJ /㎡.

The addition of PCMs with different phase change temperatures in the paper archives warehouse will cause different temperature fluctuations in the warehouse. Taking typical summer days in Guangzhou as an example, when the phase change temperature of the PCMs is -10~50 ℃ and PCM is change in every 10℃, the indoor cooling load changes hour by hour on typical days of the archives warehouse, as shown in Figure 6.

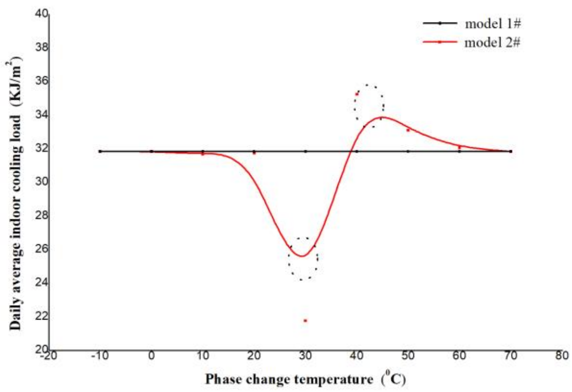

Fig. 6 Daily average indoor cooling load

From Fig. 6, when the PCM is 30℃, the $Q_{2\#}$ is minimum, specific values is 21.75KJ/㎡, η_a is 23.91%, Infer that PCMs play an important role in reducing η. When the PCM is 40℃, the $Q_{2\#}$ is maximum, numerial num is 35.23KJ/㎡, η_a is -0.09%.When the PCM is 30℃, the indoor cooling load can be reduced as shown in Figure 7.

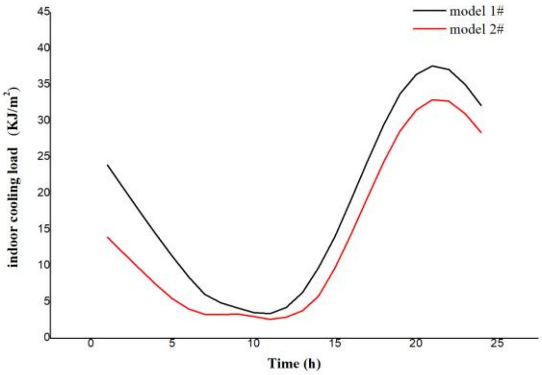

Fig. 7 Change of indoor cooling load when PCM is 30°C

As shown in Figure 7, compared with Model 1 #, Model 2 # can reduce the indoor cooling load 24 hours in a typical day after adding 30°CPCMs, and can significantly reduce the peak indoor cooling load to achieve the effect of thermal insulation. The specific impact of PCMs shall be analyzed according to the outer envelope's inter and exter temperature variation. Figure 8 shows the hourly variation of inter and exter temperature of tow models.

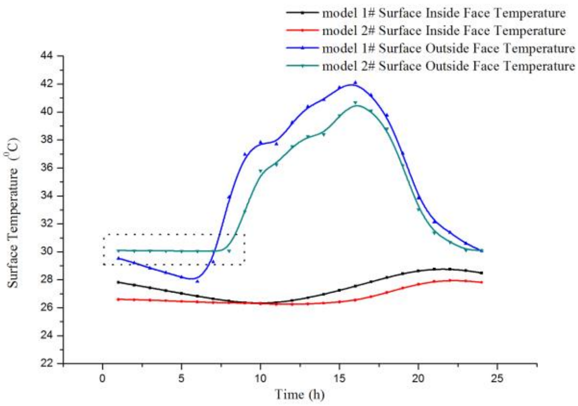

Fig. 8 Temperature change of Two Models

As shown in Figure 8, phase change platform area appears in the part of model 2 # where PCMs are added on the external surface of the wall at 01:00-08:00. During this period, PCMs occur for potential energy and energy storage. Due to the thermal inertia of the wall itself, the heat transfer is delayed. Therefore, compared with model 1#, the internal surface temperature of model 2# wall has an upward trend first, and then decreases significantly. The PCMs play an insulating role, reducing the cold load in the warehouse in typical summer days, and playing a role in energy conservation.

When the PCM is 40°C, the indoor cooling load can be increased as shown in Figure 9.

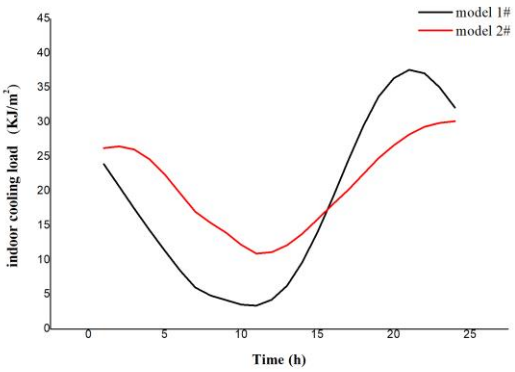

Fig. 9 Change of indoor cooling load when PCM is 40°C

From Figure 9 that when the material is 40°C, the indoor cold load of model 2 # is higher during 1:00-16:00, and the indoor cold load is higher than that of model 1 # during 16:00-24:00. On the whole, the load of model 2 # is longer than that of model 1 # in typical days. The latent heat effect and action time of PCMs can be analyzed by the inter and exter temperature of outer envelope. The inter-exter temperatures of two models are shown in Figure 10.

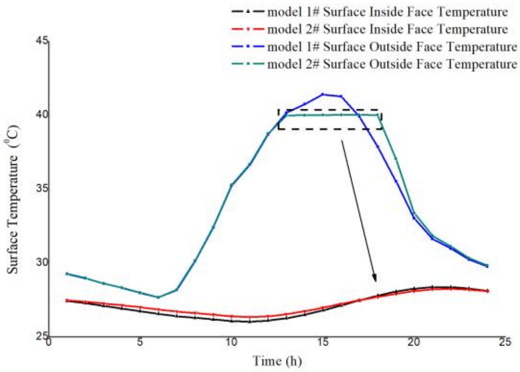

Fig. 10 Vary of surface temperature of two models

As Figure 10 showns that when 40°CPCMs are added in exterior enclosure of Model 2#, a PCM platform area appears from 13:00 to 18:00, that is, the PCMs play a role of latent heat during this period and begin to store and release energy. First, It can be seen from the comparison of the temperature varys on the inner surface that the temperature rises due to the heat release of the PCMs. With the completion of the heat release of the PCM, the temperatur decreases. Because the temperature of the inner directly contacts with the indoor air, the heat transfer is more direct, so the varys of temperature directly affectes the change of the indoor temperature, and then affects the indoor cooling load. Second, during the period from 17:00 to 18:00, the external temperature of the wall was kept at 40°C due to PCMs, which did not show the same downward trend as the external temperature of model 1#, so the PCMs did not fully play the role of thermal insulation. Based on the above two reasons, adding 40°C PCMs will increase the indoor cooling load.

When the PCMs are added outside the exterior enclosure of the archives, the time period when the

PCMs occur has a certain relationship with the impact on the indoor load. In summer, when added PCM is in the range of 20~36℃, the PCM absorbs heat in the daytime to reduce the external surface temperature of the external wall, which plays a role in heat insulation, reducing the indoor cooling load in the daytime, releasing heat at night, increasing the external surface temperature of the wall, and hindering the indoor to outdoor heat transfer. However, from the simulation results, it will only slightly increase the evening cooling load, and generally reduce the indoor cooling load. When the phase change temperature range of the PCM is about 40 ℃, the phase change period when the PCM is added to the outer layer is only in the daytime, so the PCM absorbs and releases heat in the daytime. Although it also plays the role of heat insulation, the heat release in the daytime hinders the indoor heat transfer to the outdoor. The simulation results show that the indoor cooling load will be greatly increased, so the overall indoor cooling load is increasing.

3.2 Energy saving principle of Typical Days in Lhasa

Fig. 11 summarizes the daily average indoor heating load changes of models when PCM of -10~ 50℃ are added, simulate every 10℃.

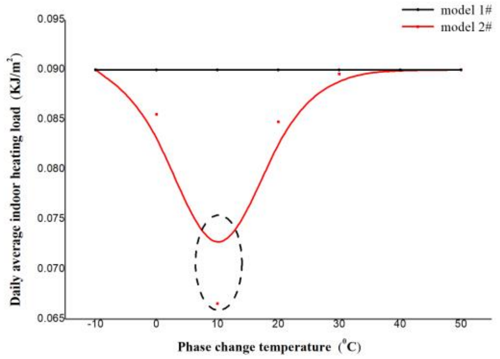

Fig. 11 Daily average indoor heating load of PCM in different temperatures

From Fig. 11 that when the PCM is about 10℃, the $Q_{2\#}$ is minimum, figure is 0.066KJ/㎡, η_a is 17.28%. In order to obtain the specific temperature of the PCM suitable for addition, it is simulated that the PCM with a temperature range of 0-20℃is added in exterior enclosure, and every 2℃is a working condition to explore the more appropriate temperature of the PCM. The specific changes are shown in Figure 12.

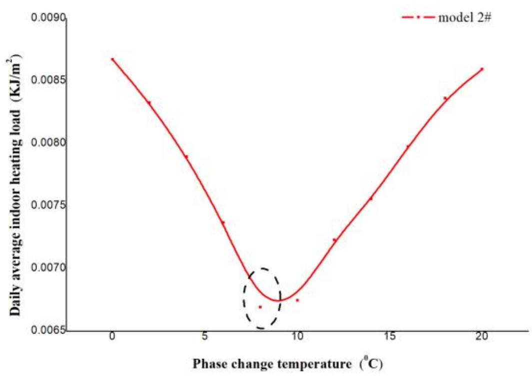

Fig. 12 Daily average indoor heating load of PCM

As shown in Figure 12, when the PCM is 8℃, the indoor cooling load can be reduced as shown in Figure 13.

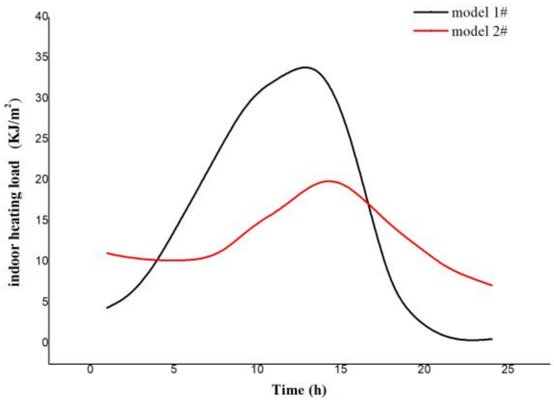

Fig. 13 Change of indoor heating load when PCM is 8℃

As shown in Figure 13, the indoor heat load of model 2 # with PCMs added during the time periods of 1:00-3:00 and 17:00-24:00 is significantly, and the indoor heat load of model 2 # is significantly lower during the time periods of 3:00-17:00. After adding PCMs, the indoor heat load decreases for longer than the increase, and the decrease is greater than the increase. The specific reasons and the principle of PCMs are shown in Figure 14.

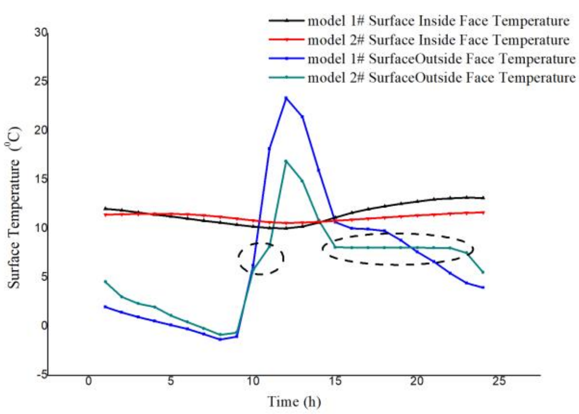

Fig. 14 Surface temperature of two model with PCM temperature is 8℃

As shown in Figure 14, since 8℃PCMs are added to the Model 2#, the temperature remains unchanged at 8℃at 11:00 and 15:00-22:00, that is a phase change plateau area appears. Due to the thermal inertia of the wall, combined with the changes of surface temperatures, the analysis shows that PCM heat storage wall decreases at 11:00, and the internal surface temperature of the PCM heat release wall increases slightly from 15:00 to 22:00. In general, the indoor heat load can be reduced by adding PCMs at 8℃.

When PCMs are added outside the enclosure of the archives, the indoor heat load can be reduced by adding PCMs with a temperature range of 0-20℃ in winter. On account of the solar radiation, the models in Lhasa is relatively high in winter, although the addition of PCMs in the outer layer will reduce the heat transfer in the daytime in winter, the release of heat at night will delay the downward trend of the surface temperature, reduce the heat transfer and heat load at night. Therefore, according to the simulation results, the indoor heat load can be reduced in general.

4 Conclusion

The following conclusions are drawn:
(1) Due to the difference of outdoor dry bulb temperature and solar irradiance in different climatic regions, the temperature of PCMs suitable for addition is also different, so it is necessary to conduct simulation analysis according to the actual situation.

(2) Analysis that adding PCMs to the outer wall can play an insulating role in the daytime and reduce the cooling energy consumption in the daytime. Through the analysis of typical summer weather in Guangzhou, the comparison of two models add PCM with 30℃to the exterior enclosure. Adding PCM can reduce the cooling load in the archive room by 23.91%. Therefore, PCM is very important for reducing indoor load.

(3) According to the analysis of the temperature changes of the interior and exterior surfaces of the walls and the indoor heat load changes in winter for three consecutive days, it can be seen that in typical winter days, the PCMs in the archives warehouse in Lhasa mostly play a role at night and are in an exothermic state, so they can effectively reduce the indoor heat load and play a role in energy conservation. Analyze the typical winter weather in Lhasa, when PCM 8℃is added to the warehouse, the indoor heating load of archives warehouse is reducing by 17.281%.

Acknowledgments

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