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Study on the Temperature Characteristics of Phase-change Energy Storage Building Materials Based on ANSYS

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To study on the temperature characteristics of the materials by using ANSYS, and establish the heat transfer equation by combining the physical model of the building material, so as to acquire the response characteristics of the internal wall temperature of the simulation wall. Compared with the temperature change of the outer wall, there was no obvious hysteresis in that of the inner wall of conventional building materials. The study on the temperature characteristics of phase-change energy storage building materials can reduce the energy consumption of the buildings, improve the energy utilization rate, and realize the intelligent temperature control of the buildings.

1. Introduction

Energy conservation has received widespread attention from various fields. Especially in energy storage technology, phase-change energy storage building materials have played a prominent role in various industries. The performance of building materials directly affects the overall quality of the building. However, the phase-change material itself has a low thermal conductivity, and therefore some measures need to be taken to improve the thermal conductivity property. The determination of thermal insulation properties of phase-change energy storage building materials is a research difficulty. Phase-change heat transfer itself has a non-linear characteristic, accompanied by liquid flow, volume change, and thermal resistance between the phase-change material and the wall, which makes it very difficult to analyze the thermal performance.
At present, the large amount of energy consumed has led to the deterioration of the ecological environment. The development of renewable energy and the exploitation of new energy have an important role in the social development, which are also the key projects of China's medium- and long-term scientific and technological development plan. In this study, phase-change energy storage materials were prepared by combining the paraffin wax phase-change energy storage microcapsules and the gypsum substrates, and by testing the response relationship between the wall temperature and the ambient temperature, simulate the corresponding laws of temperature, and then acquire the final results by combining the heat transfer equation. The use of phase-change energy storage building materials needs to take such factors as the type of phase-change material, the phase-change temperature range, the percentage of compounding with traditional materials, the climate of the application area, and the use of the structure of the building, etc. into account. A further study on the heat transfer model of phase-change energy storage building materials, the design of various components and phase-change systems, etc. is still required.

2. Literature review

In 1982, the U.S. Department of Energy took the lead in applying phase change energy storage materials to building materials to form phase change energy storage building envelopes. Since the 1980s, scholars and researchers from all over the world have started a boom in research on phase change materials. Phase change energy storage materials referred to as PCM. It is a type of material that can absorb the amount of heat (cold) of the environment during the phase transition itself, and release the amount of heat (cold) to the environment when needed, so as to achieve the purpose of controlling the ambient temperature. The phase change energy storage material and concrete and other building materials can be made into a phase change

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energy storage building wall or other heat preservation structure. The building energy-saving energy storage methods are generally divided into sensible heat and latent heat, but the two have different heat storage effects. Compared with the former, the latter has a more significant energy storage effect. The transition temperature and the enthalpy of phase transition have wider selection range. The heat stored in latent heat storage is several ten times that of sensible heat. Using this feature, phase change energy storage materials can be applied to many aspects, such as aerospace, modern weapons, building envelopes, etc., which have broad prospects. At the end of the 20th century, phase change energy storage technology was developed. A combination of phase change materials and building materials has developed a series of gypsum boards and phase change building walls. Since phase change material technology is not mature enough, the types of materials are insufficient, and the cost is too high, phase change materials have not been practically used in production. In 1999, phase change energy storage technology was further developed. A new type of solid-liquid eutectic phase change material was first developed in foreign countries. This material is added to the building wall. It can maintain a moderate temperature in the indoor environment for a long time. Many companies have used this technology to build many huts for outdoor communication or power equipment that can keep these devices from freezing. In addition, phase change materials can also be added when laying asphalt on cement pavement to prevent road surface from freezing and improve road safety.

At present, many domestic and foreign researchers and institutions are working hard to further explore the great potential of phase change materials. Previous researchers have studied various ways to integrate PCMS into building structures. It has been found that with the help of PCMS, the indoor temperature fluctuations can be significantly reduced while maintaining the desired thermal comfort. Zhou et al. summarized previous work on latent heat storage, covering PCM, impregnation methods, current building applications and thermal performance analysis, and numerical simulation of PCM buildings in building applications (Zhou et al., 2013). Huang et al. used a eutectic mixture as a phase change energy storage material (PCMS) and a high-density polyethylene (HDPE)-ethylene-vinyl acetate (Eva) polymer as raw materials. A series of morphologically stable phase change materials (FSPCMS) were prepared and analyzed. Research shows that FSPCMS can be used as a potential building heat storage material. It is extremely satisfactory in terms of thermal properties (Huang et al., 2013). Chang et al. prepared a binary organic/inorganic nanocomposite PCM prepared by intercalation compounds, systematically studied the preparation conditions, and performed structural analysis and performance characterization. The results show that nano-composite PCM has good heating and cooling potential in buildings. It overcomes the shortcomings and deficiencies of pure PCM (Chang et al., 2013). The possible incorporation of phase change materials (PCMS) in building materials has attracted worldwide research interest due to concerns of global warming and PCM energy storage capabilities. It can reduce the energy consumption of the building. PCM is a substance with high heat of fusion. It can store and release large amounts of energy in the form of heat during melting and solidification at a specific transition temperature. During the past 20 years, a great deal of research has been conducted on the potential application of PCM in concrete. The results show that PCM concrete has good latent heat storage and thermal properties. In addition, phase change materials have a certain negative impact on the performance of concrete. However, if proper PCM and proper incorporation methods are used during PCM concrete production, negative effects can be reduced. Ling et al. studied the different types of phase change materials and their incorporation methods, and the effect of PCMS on the performance of concrete in the freshness and hardening stages, and introduced the stability of PCMS, the use of them in concrete and the thermal properties of them in concrete (Ling et al., 2013). Kheradmand et al. studied the feasibility of phase change material impregnation (PCMS) in lightweight aggregates (LWAS). Immersion was used to study the embedding of two different PCMSs in four different LWAS. Studies have shown that the impregnation/embedding method is effective at large energy storage densities. It can be applied to situations where PCMS cannot be directly incorporated, such as asphalt pavement (Kheradmand et al., 2015). Fan et al. studied the use of paraffinic liquid and stearic acid as raw materials to obtain a phase change energy storage material suitable for buildings with a mass fraction of 78:22. Its melting temperature can be adjusted from 25°C to 35°C, and solves the problems of easy leakage of phase change materials, and compatibility with aggregates and cement. It provides a cost-effective way for the utilization of waste autoclaved aerated concrete (Fan et al., 2016). The eutectic mixture of sebacic acid stearate (S-C) was incorporated into activated attapulgite (A-ATP), which was used as a support material in the composite. A novel low temperature latent heat storage (FSPCM) stable phase change energy storage material (FSPCM) was prepared. A-ATP is an open tubular capillary with a large specific surface area that facilitates the adsorption of PCMS. Research shows that S/C/ATP FSPCM is an effective energy-saving LTE building material (Song et al., 2014). Konuklu et al. studied various packaging techniques, test methods, and application of MPCMS in construction of MPCMS. There are several microencapsulation methods that can prepare microcapsules with a size of 0.0502 μm to 500 002 μm. In combination with concrete, mortar, gypsum and other materials, MPCM has the potential to significantly increase the heat capacity of the mixture. Although the increase in heat capacity is significant after the addition of MPCM, the decrease in mechanical properties such as compressive strength is relatively small (Konuklu et al., 2015).

In summary, although scholars at home and abroad have studied many types of phase change materials, there are still many problems, such as immature technologies, insufficient types of phase change materials, and poor heat storage effects. Phase change materials are still a long way from mass production. Therefore, the performance and energy storage technology of PCM are very important for the further development of PCM. It is conducive to developing temperature regulating wall materials and responding to energy saving policies implemented by the government. Based on the above research status, the temperature characteristics of phase change energy storage building materials are further studied using ANSYS software.

3. Method

Phase-change energy storage is mainly to realize the storage of energy generated from the latent heat of phase-change absorbed or released during the phase-change process, along with the change of material phase within specific temperature or temperature range by phase-change energy storage materials, and latent heat storage energy of phase-change is composed of high temperature latent heat storage energy and low temperature latent heat storage. High-temperature latent heat storage is mainly used in solar power plants, magnetic fluids and other related fields. Low-temperature latent heat storage is mainly used in air conditioning and heating systems and other related systems and waste heat recovery related fields. The advantages of phase-change energy storage technology feature high heat storage density, stable heat storage process, small storage device size, low price, easy implementation, and wide application range. Disadvantages lie in leakage, and low thermal conductivity, etc. At present, phase-change energy storage technology has become the most promising, the most widely used and most important material, and has become a hot topic in energy utilization and material science research at home and abroad. Incorporating phase-change materials into traditional thermal insulation materials to prepare new types of high-efficiency and energy-saving building wall materials has considerable research value, and will also produce significant environmental and economic benefits. Phase-change material is a kind of thermal functional material that can store the energy in the form of latent heat of phase-change and then release the stored energy according to different demands. From the chemical composition of materials, phase-change materials can be divided into inorganic category and organic category. Among them, inorganic phase-change materials mainly include crystalline hydrous salts, metals, and alloys thereof; organic phase-change materials mainly include such organic substances as paraffin wax, polyhydric alcohols, capric acid, and palmitic acid. Two important factors that limit the practical application of phase-change materials are the phase transition temperature and the thermal conductivity. The magnitude of the thermal conductivity is related to the power of energy storage and energy release of the energy storage device. If the thermal conductivity is too low, then during the practical applications, the energy storage device cannot fully utilize the heat stored by phase-change material contained therein.

The β-gypsum and paraffin energy storage microcapsules are mixed according to a certain ratio, and then water is added at a mass ratio of 100: 60 (β-gypsum vs. water)comparing with β-gypsum, and the mixture is stirred until the system has a certain viscosity and then is poured into a forming mold to for setting and solidifying process, in which, β - Gypsum and water generate the hydration reaction, as shown in Figure 1.

$$\beta\text{-}CaSO_4 + 1.5H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

Figure 1: The hydration reaction

The acicular crystals of dihydrate gypsum produced during the hydration process grow alternately and connect with each other, resulting in the coagulation and hardening of the gypsum slurry. After the gypsum board in the mold has a certain strength, open the mold and remove the board out, the gypsum-base paraffin phase-change energy storage building material plate is acquired. According to the above method, the phase-change energy storage building material is prepared into a test block, in which, a thermocouple is embedded, and after the connection, the thermocouple and the testing system are placed outdoor environment for conducting the temperature change response test. The test system is as shown in Figure 2, and the test results are as shown in Figure 3.

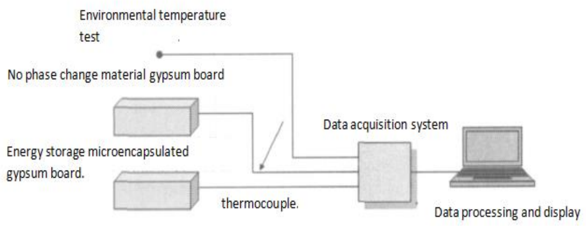

Figure 2: The response of wall temperature to environmental temperature change

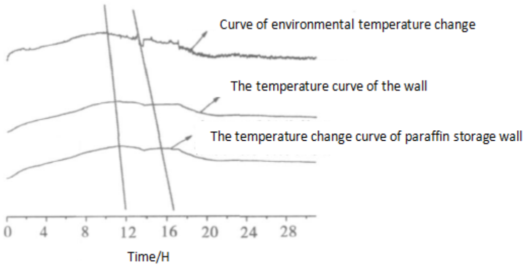

Figure 3: The response curve of temperature change of wall environment of phase-change energy storage building materials

It can be seen that the time for temperature change response curve of the paraffin-containing energy storage microcapsule sample to reach a temperature peak is longer than that of the phase-change-free energy storage microcapsule sample, and the duration of the relatively stable temperature is also longer. Therefore, the introduction of phase-change energy storage materials into the building matrix material has a positive effect on maintaining a constant temperature of the building and reducing the cooling energy consumption of the building. Unlike general composite materials, the specific heat capacity of composite materials containing phase-change materials (PCMs) around the phase transition temperature is not a constant, but rather a strong temperature dependence, which would make it difficult for analytical method to be applied to determine the transient thermal properties of phase-change composites, and however, if the transient thermal conductance of composites containing phase-change materials is not simplified and two-dimensional and three-dimensional numerical simulations are applied directly, in many cases, it does not only involve a big amount of calculation, but is also unnecessary. This study establishes a related heat transfer mathematical model by simplifying the physical model of the material, and by adopting ANSYS to conduct the simulation analysis, obtains the response characteristics of different samples facing temperature changes. In this study, phase-change energy storage microcapsules are mixed with conventional building material gypsum to obtain the building materials with energy storage capabilities as shown in Figure 4.

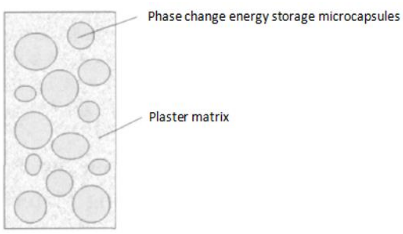

Figure 4: Profile of gypsum matrix phase-change energy storage material

Since the arrangement of the microcapsules in the matrix structure is irregular, this brings great difficulties for mathematical description. To simplify the solution of the problem, assume that a part of the substrate structure is intercepted with a height much bigger than that of the structure, and assume that the arrangement of the micro-capsule within the intercepted height is regular and ignore the influence on heat transfer of micro-capsule between micro-capsules, the structure of the composite energy storage materials may be divided into

3 parts, among which, the inner layer and the outer layer are gypsum horizon, and the middle layer is phase-change material layer. It is assumed to adopt the gypsum-based paraffin wax phase-change energy storage material to serve as the wall structure of air-conditioning building, and ignore the humidity factor, the harasses suffered during the heat transfer mainly include two parts, the indoor part, i.e. realizing the heat dissipation of inner surface through people, equipment and indoor air, etc.; the outdoor part, i.e. realizing the heat dissipation of outer space through the sun, outdoor air, etc. For air-conditioning building, it's generally considered that the temperature of the inner surface of the outer structure is constant, while the outdoor only considers the periodical effect of the sun and outdoor air.

4. Results and discussion

Assuming that the thermal conductivity of the gypsum board with paraffin phase-change energy storage microcapsules does not change with temperature, and the ambient temperature changes continuously and periodically, with the maximum temperature in one day at 32°C, and the minimum temperature at 18°C, then the daily temperature change curve is as shown in Figure 5.

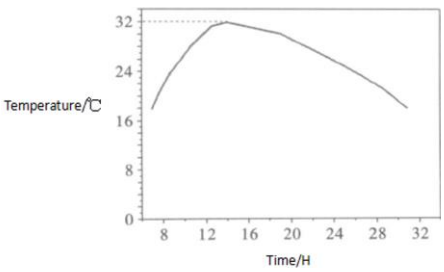

Figure 5: The daily temperature curve

Since the temperature is a continuous variable, it requires to establish the time function and the temperature function by stage in ANSYS, and for this test, the function is established in 2 stages, so as to represents the temperature change within 1 day. The temperature rising section is represented through approximate fitting by adopting parabolic equation, and the temperature drop section is represented through approximate fitting by adopting cosine function. The enthalpy of phase-change energy storage paraffin is an amount that changes with temperature, and inputting the enthalpy values at different temperatures, the enthalpy value curve acquired by value interpolation that changes with temperature is as shown in Figure 6.

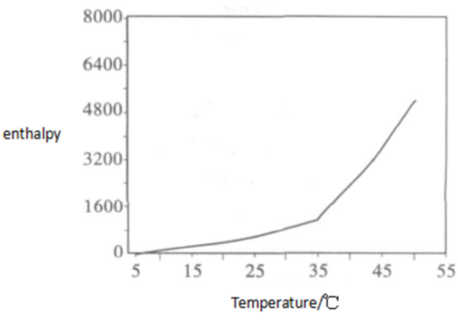

Figure 6: The change of enthalpy of paraffin wax with the change of temperature of ANSYS

It can be seen from the curve of the temperature changes of the inner wall surface and outer wall surface of different gypsum board samples obtained from the simulation that the there's almost no hysteresis during the response of inner wall surface temperature to the outer wall surface temperature change, and there's no relatively constant stage in temperature. After the gypsum board is added with paraffin wax storage energy micro-capsules, there's hysteresis during the response of inner wall surface temperature to the outer wall surface temperature change, and relatively constant stage in temperature exists and the highest temperature is also low, due to the latent heat storage energy, the temperature is relatively constant in phase change range. Comparing with the actual test results, it can be seen that the simulation results are consistent with the test results, which indicates that the simplification of simulation physical model and the establishment of heat transfer equation are more accurately.

This Paper tests the response of wall temperature of phase-change energy storage composite materials acquired from the paraffin phase-change energy storage micro-capsule and gypsum matrix composite to the environmental temperature, and the results show that, comparing with phase-change-free energy storage micro-capsule, the time that the temperature change response curve reaches the temperature peak is lagged behind, and the time of duration with relatively stable temperature is relatively long. The heat transfer equation was established by simplifying the physical model, which conducts the analogue simulation of the response characteristics of inner wall surface temperature change of different gypsum board specimens to the outer wall surface temperature change, and the results show that, after adding the paraffin phase change storage microcapsules, there's hysteresis during the response of inner wall surface temperature to the outer wall surface temperature change and the relatively constant stage of temperature exists, and the peak temperature is also low, i.e. the simulation results are consistent with the test results, which shows that the establishment and simplification of the model are relatively accurate. During the practical application, the phase-change energy storage materials are introduced into building materials, and since the building would have huge heat capacity due to the latent heat energy storage of phase change materials, so as to reach the purpose of reducing the inner temperature of the building and decreasing the capacity of the air conditioning refrigeration system of the building, offering a good way for reducing the energy consumption and cost of building cooling.

5. Conclusions

Phase-change energy storage materials have attracted the attention of researchers because of their good heat storage and heat release mechanisms. Phase-change energy storage materials can store such energy as waste heat or solar energy, etc. so that energy can be effectively used and the use of non-renewable energy such as oil can be reduced. In modern society, people's demands for a comfortable and beautiful life are growing, such as a comfortable living environment, and exquisite and convenient daily necessities, etc. However, most of these demands cannot be achieved without energy supply.

Currently, phase-change energy storage building materials with special functions are the focus of the study, and the research on thermal properties and stability needs also requires further development. The simulation results in this Paper are consistent with the test results. It also shows that the phase-change materials in the future will have a significant effect on the building energy conservation of energy storage materials, allowing the building to gradually become green, environmentally friendly, and more closely integrated with other materials, for example, how to improve the enthalpy of phase-change based on the phase-change mechanism, based on which, develop the phase-change materials with high energy density.

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