Energy saving application of phase change materials in buildings: A comprehensive review

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Abstract. The theoretical basis of the preparation of phase change energy storage materials is analyzed firstly, and then the preparation methods of fatty acid phase change energy storage materials are analyzed in detail. Furthermore, the application of phase change energy storage materials in building energy saving is analyzed. Finally, combined with the above contents, the application prospect and research direction of phase change energy storage materials are briefly described.

1. Introduction
Phase change energy storage materials, also known as latent heat storage materials, can store energy by absorbing and releasing heat in the phase change process of materials. Phase change energy storage materials have the advantages of high energy storage density, stable output temperature, which are of great significance for improving energy utilization and energy structure. The scientific understanding and research of phase change energy storage materials began in the 1950s. In recent years, with the shortage of energy, many researchers have carried out a lot of research. Some phase change materials have been commercialized. The research of phase change energy storage materials shows the trend from inorganic to organic, from single component to composite components, from macro-encapsulating to micro-encapsulating. The application of phase change energy storage materials has gradually expanded to military, aviation and other fields from solar energy utilization. In this paper, the latest research progress and application of phase change materials are reviewed, and the future research directions are prospected.

2. Summary of phase change energy storage materials
Phase change energy storage materials generally refer to materials that absorb heat (cold) from the environment and release it to the environment in the process of phase change, so as to regulate the comfort of the surrounding environment and achieve the purpose of energy saving and emission reduction [1-3]. Phase change energy storage materials occur under isothermal or approximate isothermal conditions. The process is accompanied by a large amount of energy absorption or release. This characteristic makes phase change energy storage materials become the theoretical basis for improving energy utilization. At present, inorganic and organic phase change materials are the two most commonly used phase change energy storage materials. Most inorganic phase change energy storage materials have the disadvantage of super-cooling and phase separation in the phase change process, and can cause corrosion to the building structure, while the chemical properties of organic phase change energy storage materials are relatively stable. Therefore, organic
phase change materials have a wider range of applications. However, there are fewer monolithic phase change materials which can be used in the field of low-temperature energy storage, and the cost of using a phase change material is higher. It is also difficult to meet the requirements of phase change temperature and enthalpy for building energy storage at the same time [5]. Therefore, binary or multi-component composites of phase change energy storage materials are the future research direction.

3. Preparation principle of phase change materials
Material with variable function is usually difficult to be used directly. In most cases, it is necessary to compound it with the carrier to form a material that can maintain solid shape. The common preparation methods of phase change materials include adsorption encapsulation, physical mixing, and chemical modification [6-7]. Adsorption encapsulation is divided into macro-encapsulation and micro-encapsulation. Macro-encapsulation encapsulating is to encapsulate phase change materials in containers with a certain shape to make a specific heat storage device. Micro-encapsulation is a new encapsulation technology in recent years. Some inorganic materials are used as shell materials to encapsulate phase change materials. It can not only avoid leakage of phase change materials in solid-liquid phase change process, but also increase the heat transfer area and enhance the heat transfer effect. Based on this, Gu [8] used expanded perlite as carrier to adsorb lauryl alcohol. Ten groups of composite phase change materials with different proportions were tested by leakage test. The results showed that when the mass fraction of lauryl alcohol was 40%, the adsorption effect was the best. The shape-stabilized phase change material was prepared by physical adsorption method, and its structure and properties were tested by XRD and other testing methods. The mass percentage of each component in the shape-stabilized phase change material could be determined, so that the shape-stabilized phase change material with relatively stable thermo-physical properties could be prepared [9-11]. Liu [12] studied the properties of expanded graphite-based phase change materials and the relationship between the properties. It is concluded that the content of graphite is the main factor affecting the properties of expanded graphite-based phase change materials. Physical blending method is to mix phase change materials with carriers. Polymer materials are used as carriers to disperse solid-liquid phase change materials and form composite phase change materials by physical interaction. This method requires that phase change materials and carriers do not react chemically and have good compatibility. In the process of phase change, the three-dimensional interlacing network of polymer chains can restrain the flow of liquid, so that the material can be finalized. Fang [13] blended polyethylene glycol with epoxy resin to prepare shape-stabilized phase change material, which effectively prevented the leakage of PEG. The composite exhibited the characteristics of solid-solid phase change material. Chemical modification is used to transform the phase change material into a new type of compound, which can not only maintain the energy storage characteristics, but also meet the application requirements. For example, Na$_2$SO$_4$/SiO$_2$ nanocomposite was prepared by sol-gel method using tetraethyl orthosilicate as silicon materials [14]. Mu [15] used copolymer of acrylonitrile and itaconic acid and polyethylene glycol to prepare phase change materials. The latent heat of phase change was 57-97J/g, and the temperature of phase change was 22-53°C.

4. Energy saving application of phase change materials
Phase change energy storage materials have not only made some achievements in preparation, but also been applied in building energy saving and other fields. The incorporation of a certain amount of phase change energy storage materials into building materials can not only improve the thermal insulation performance of buildings, reduce the building energy consumption of air conditioning and other equipment, but also adjust the indoor temperature of buildings, which has a certain application prospect [16]. Hu [17] mixed phase change paraffin and gypsum to prepare phase change energy storage gypsum. The thermal performance of phase change energy storage gypsum was simulated by finite element software. The results show that the thermal storage effect of phase change energy storage gypsum added to building walls is obvious. Kong [18] established a mathematical model and analyzed the influencing factors of heat transfer performance of phase change energy storage wall. The
results show that the indoor effect of phase change materials is obvious corresponding to the climate characteristics in summer. The temperature fluctuation of phase change materials can be simulated by finite element software, and can be verified by experiments [19]. Using gypsum as carrier and binary composite phase change material as raw material to prepare phase change energy storage gypsum, a series of valuable conclusions can be drawn by studying its properties. Xiao [21] prepared dodecanol/bentonite composite phase change material by ultrasonic vibration and liquid phase intercalation. After several thermal cycles, the thermal properties of the composite phase change material remained stable. The results showed that the composite phase change material had good compatibility with gypsum, and could be made into phase change gypsum board, which had good thermal insulation performance. The phase change energy storage gypsum prepared by direct mixing method can not only compare the performance difference between phase change energy storage gypsum and ordinary gypsum, but also further measure the energy storage capacity of phase change energy storage gypsum board [22]. Ou [23] studied the relationship between the content of phase change microcapsules and the fluidity, apparent density, flexural strength and compressive strength of mortar. The results show that the optimum mass fraction of phase change microcapsules to replace quartz sand is 10%. At this time, the compressive strength of mortar increases by 37.1% compared with that of mortar without phase change microcapsules. Liu [24] combined cement mortar with binary eutectic hydrate/expanded graphite oxide stabilized composite phase change materials and polyacrylamide-acrylic copolymer stabilized phase change materials to prepare two kinds of energy storage cement-based composites. The results show that the maximum temperature difference is 5.0°C and 6.7°C respectively. Li Xiaohui et al. [25] prepared phase change energy storage aggregate by porous material adsorbing phase change material, and then added it to concrete to prepare phase change energy storage concrete. The experimental results show that a large number of phase change materials can be embedded in concrete by two-step preparation method, so that the thermal storage performance of phase change concrete is good.

5. Conclusions
Based on the current situation of phase change energy storage materials, the research directions of composite technology and future energy storage materials are analyzed and elaborated in this paper. It is also hoped to provide new ideas for the rapid development of the industry and provide value and basis for the effective application of phase change energy storage materials in building materials. With the deepening of research in recent years, researchers have made many progresses in the physical properties of phase change materials and their composite preparation, and their applications have also been promoted. However, at present, phase change materials generally have some problems, such as low thermal conductivity, poor mechanical properties and chemical stability, high cost, leakage of liquid and so on. How to solve the above problems and realize the practical application of phase change energy storage materials in various fields are a challenging subject and an important development direction. The development trend in the future can be summarized as follows:

(1) According to different requirements, phase change materials with suitable phase change temperature, high phase change enthalpy, low cost and stable physical and chemical properties in long-term use can be developed.

(2) According to different climatic conditions, phase change materials suitable for different environmental conditions can be developed.

(3) According to different types of building structures, the application of phase change materials in energy saving of building walls can be studied, especially the influence of thermal bridge.

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