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The Application of Phase Change Energy Storage Materials in Building Energy Conservation

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Abstract: With the proposal of the concept of "green building", building energy conservation has become a hot topic today. Because of their many advantages, phase change materials (PCMs) have played an exemplary role in the field of building energy conservation, but there are still some problems. In this paper, we introduce the concept, classification and specific application of PCMs, and their future development is prospected.

Keywords: Phase Change Materials (PCMs); Composite Materials; Building Energy Conservation.

1. Background

With the rapid development of modern society and economy, the enormous energy demand in human society has led to increasingly serious energy shortages and environmental pollution problems. It is necessary to improve energy utilization efficiency and achieve sustainable energy development. The development of architecture is closely related to the development of society, economy, and culture, and is also inseparable from human needs. Since its inception, green buildings have focused on the relationship between buildings, the environment, and energy, emphasizing energy conservation and reducing environmental loads. In recent years, with the improvement of productivity and the further improvement of people's requirements for the quality of living and working environments, people have gradually shifted the relationship between buildings and the environment back to the relationship between buildings and people, emphasizing people-oriented and promoting harmonious development between humans and nature [1-2]

1.1. Foreign Development

Since 2015, with the strong promotion of various countries, developing green buildings, reducing energy consumption and environmental pollution, and striving to achieve harmony and unity among architecture, nature, and people have become a consensus in the global construction industry development. As of the end of 2020, North America, Europe, and the Asia Pacific region were the three major global green building markets, and North America and Europe are still leading the development of green buildings [3]. In 2015, Germany released a new version of the passive housing standard. In 2017, the Future Living Council of the United States revised its zero-energy certification standard, and the World Green Building Council proposed the goal of "all zero carbon buildings by 2050". In 2019, the US Green Building Council released the LEED zero energy and zero carbon certification system [4].

1.2. Domestic Development

During the 13th Five Year Plan period, China's overall development of green buildings has entered a new stage of comprehensive and high-speed development, with approximately 3500 new green building identification projects added annually. According to the current engineering organization in China, green buildings mainly include three stages, namely green project approval, green design, and green construction (Figure 1). In 2019, China issued and implemented the "Technical Standards for Near Zero Energy Buildings" GB/T 51350-2019, proposing a "three step" energy efficiency improvement route for ultra-low energy buildings, near zero energy buildings, and zero energy buildings [5]. At the same time, the incremental costs of green buildings have significantly decreased. From 2010 to 2020, the incremental costs of first, second, and three-star public buildings and residential buildings have decreased by 47%, 52%, 66%, and 36%, 71%, and 80%, respectively. The higher the level of green buildings, the more significant the decrease in incremental costs [6]. China's research on achieving carbon neutrality in buildings, key technologies for building thermal environment, steel structures and sustainable development has also provided theoretical basis and technical guidance for the further implementation of green buildings [7].

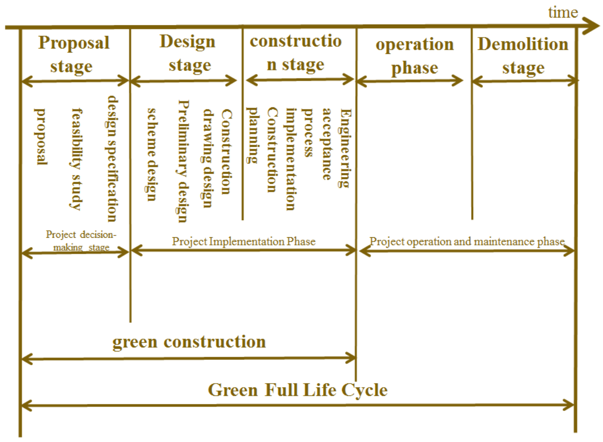

Fig 1. Green building construction stage division

Image source: Green Building Development Report: Green Building Leading the Transformation and Upgrading of Urban and Rural Construction. Beijing: China Construction Industry Press, July 2022

2. Concept of Phase Change Energy Storage Materials

In people's daily lives, most of the energy is used in the form of thermal energy [8]. Therefore, energy storage and thermal management are considered an effective strategy for achieving sustainable energy development. The storage methods of thermal energy are divided into latent heat, sensible heat, and chemical heat storage, and the principle of latent heat storage is the mainstream [9]. The latent heat storage method has been widely studied due to its compact structure and ability to store energy at nearly constant temperatures corresponding to the material phase transition temperature. It mainly utilizes phase change materials (PCMs) to store heat, thereby achieving higher energy utilization rates [10-11]. Phase change energy storage materials (PCMs) maintain their temperature within a certain range during the process of phase change, and absorb and release much more heat than general sensible heat storage materials (Figure 2). They have a higher energy density and therefore have significant success in building energy conservation, making them a key carrier of phase change energy storage technology.

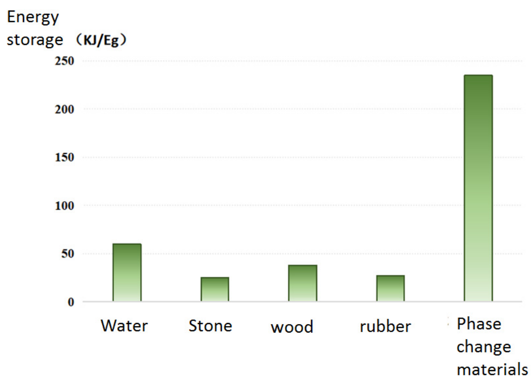

Fig 2. Phase change materials and other energy storage comparison of general materials [8]

2.1. Research History

The first person to study phase change energy storage materials was Hungarian scientist M Telkes began researching how phase change materials store solar energy as early as the early 1940s. In the 1960s, NASA began to integrate phase change materials with the aerospace field, ushering in a new era of human research on phase change materials [12]. Later, China began to research phase change materials, mainly in the fields of metals and inorganic hydrated salts.

With the continuous deepening and maturity of technology in our country, phase change materials have been widely used in fields such as thermal protection of electronic components, thermal control of power batteries, solar energy storage, industrial waste heat recovery, energy-saving materials for buildings, and temperature regulating clothing in recent years [13].

In terms of building energy efficiency, due to China's vast territory and significant climate differences, the materials used in different regions are not the same. However, currently, there are polyols, crystalline hydrated salts, high polymer polymers, and so on.

2.2. Thermal Conductivity Mechanism

The heat transfer process of phase change heat storage materials is shown in Figure 3, mainly including[14]; (1) Heat energy is transferred to atoms on the surface of the material to obtain vibrational energy; (2) Surface atoms transfer heat energy to adjacent atoms at the same frequency and speed; (3) Thermal energy enters the entire crystal in a common vibrational wave mode; (4) When heat reaches another surface of the material, it can be partially transferred to the surrounding environment through conduction or radiation. From the perspective of microscopic mechanisms, it was found that the thermal conductivity of metal phase change heat storage materials is mainly controlled by electrons, and its thermal conductivity relies on the interaction between free electrons and phonons [15]. When the distance between the movement of free electrons inside and outside the nucleus of a metal is much greater than the distance between atomic interactions, electrons will gain greater energy and become the main hot carrier [16].

Fig 3. Heat transfer diagram in crystal heat conduction [14]

2.3. Preparation Method

Materials with phase change properties are generally not suitable for direct use alone. Considering that phase changes in materials can affect the performance of other materials, it is usually necessary to composite them with the carrier to form a fixed state material for utilization. The main methods for preparing composite phase change materials include encapsulation, impregnation, physical blending, etc. [17].

Packaging methods are divided into macro packaging and micro packaging. Macroencapsulation refers to the encapsulation of phase change materials in selected containers (such as tubes, shells, plates, etc.) to create a unique heat storage system. Microencapsulation refers to the microcapsule method, which uses phase change materials as the core and is wrapped in polymers or inorganic substances. Wang H.[18] A spherical microcapsule phase change material was prepared by encapsulating n-octadecane with Ag/SiO2. The impregnation method refers to the preparation of composite phase change materials using a matrix (bentonite, expanded perlite, expanded vermiculite, etc.) with rich pores or pores as the carrier, relying on its capillary force to adsorb the molten phase change materials. It is divided into vacuum impregnation method and direct impregnation method. Zhao Sixie et al [19] The lauric acid expanded perlite composite phase change material was prepared by vacuum impregnation, and the highest content of lauric acid in the composite phase change material can be reached. The physical blending method refers to the mixing of a carrier and a phase change material, usually using a polymer material as the carrier. The solid-liquid phase change material is evenly dispersed among them, and a composite phase change material is synthesized under physical effects. Liu Fengli et al [20] The organic expanded vermiculite composite phase change material with sebacate stearic acid was prepared by melt blending method. The phase change temperature was 21.48 °C, and the latent heat of phase change was 61.65J/g. After 100 thermal cycles, the thermal stability was good.

3. Classification of Phase Change Energy Storage Materials

3.1. Inorganic Phase Change Materials

As shown in Table 1, inorganic phase change materials mainly include crystalline hydrated salts, molten salts, and metal alloys [22]. Because the phase change temperature of crystalline hydrated salts inorganic phase change materials is mostly between 0 to 150 ℃, and they also have advantages such as low price, low toxicity, high thermal conductivity, large density, small volume, and large phase change latent heat, they are widely used in various fields such as building energy conservation and industrial waste heat recovery. Molten salts and metal alloy materials have advantages such as high thermal conductivity and high energy storage density, and are commonly used in aerospace and other fields. However, inorganic phase change materials all have a common drawback: due to improper temperature control during use, supercooling and phase separation are prone to occur, which greatly reduces their applicability.

Table 1. Common inorganic phase change materials [22]

Name	Type	T_m/℃	ΔH_m/(J·g^{-1})
$LiClO_3·3H_2O$	Hydrous salt	8.1	253
$KF·4H_2O$	Hydrous salt	18.5	231
$Mn(NO_3)_2·6H_2O$	Hydrous salt	25.8	126
$CaCl_2·6H_2O$	Hydrous salt	29	190
$Na_2SO_4·10H_2O$	Hydrous salt	32.4	254
$Zn(NO_3)_2·6H_2O$	Hydrous salt	36	147
$Na_2HPO_4·7H_2O$	Hydrous salt	48	201
$Na_2P_4O_7·12H_2O$	Hydrous salt	70	184
KNO_3	Hydrous salt	333	266
$MgCl_2$	Salt	714	452
KF	Salt	857	452
K_2CO_3	Salt	897	258
Al	Metal	660	395
Cu	Metal	1 083	203
Zn	Metal	419	103
Mg	Metal	651	377

3.2. Organic Phase Change Materials

As shown in Table 2, organic phase change materials mainly include lipids, carboxylic acids, alkanes, alcohols, etc. Unlike inorganic phase change materials, there are relatively more types of organic phase change materials, which have a regular phase change temperature within a certain range, and have the advantage of a wide range of phase change temperature and latent heat. The phase transition temperature and enthalpy of most organic phase change materials increase with the extension of their carbon chains, and can utilize the ordered disordered alternating arrangement of molecules for heat storage and release, achieving precise temperature regulation. In addition, organic phase change materials also have advantages such as low price, high energy storage density, and non corrosiveness. However, there are also shortcomings such as low thermal conductivity, volatility, and flammability during use.

Table 2. Commonly used organic phase change materials [22]

Name	Type	T_m/℃	ΔH_m/(J·g^{-1})
Wax	Alkane	4～70	150～190
n-Tetradecane	Alkane	6	227
n-Hexadecane	Alkane	18.5	236
n-Octadecane	Alkane	28.1	244
n-Eicosane	Alkane	37	248
Octanoic acid	Carboxylic acids	16	149
Decylic acid	Carboxylic acids	32	153
Lauric acid	Carboxylic acids	44	178
Tetradecanoic acid	Carboxylic acids	51	205
Dodecanol	Alcohol	26	200
Tetradecanol	Alcohol	38	205

3.3. Composite Phase Change Materials

As shown in Table 3, composite phase change materials are composed of two or more types of phase change materials through physical or chemical methods, roughly divided into three situations: inorganic composite, inorganic organic composite, and organic composite, in order to composite an ideal phase change material and achieve better energy storage effect.

Table 3. Common composite phase change materials [22]

Name	T_m/℃	ΔH_m/(J·g^{-1})
66.6% $CaCl_2·6H_2O$+33.3% $MgCl_2·6H_2O$	25	127.0
14% $LiNO_3$+86%$Mg(NO_3)_2·6H_2O$	72	180.0
34% Tetradecanoic acid+66% Decylic acid	24	147.7

4. The Specific Application of Phase Change Materials in Building Energy Conservation

The substrate of phase change energy storage buildings should meet the following characteristics: being able to absorb and release an appropriate amount of heat energy, being able to be used simultaneously with other traditional building materials, not requiring special knowledge and skills to install and use thermal storage building materials, being able to produce using standard production equipment, and being competitive in economic benefits [23]. From the perspective of building energy consumption ratio, wall energy consumption accounts for the largest proportion of building energy consumption. Therefore, the development and application of energy-saving and insulation materials for walls will play a crucial role in building energy conservation [24]. According to practical energy consumption statistical research, if insulation and energy-saving measures are not taken for residential buildings in northern China, the proportion of indoor energy consumption in various parts of the building to the total energy consumption is shown in Figure 4. It can be seen that the energy consumption of buildings in China is mainly reflected in walls and doors and windows. To reduce building energy consumption: firstly, control indoor temperature; secondly, reduce external heat dissipation of the building.

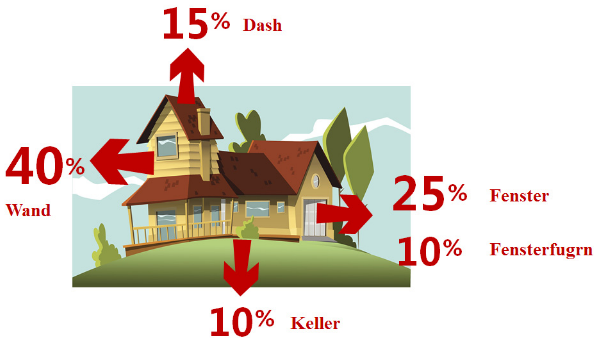

Fig 4. Schematic diagram of energy consumption ratio of various parts of the building [24]

4.1. Application of Phase Change Materials in Walls

4.1.1. Development of Phase Change Energy Storage Wall Panels

At present, the building substrates that can be used as phase change walls include gypsum board, plaster board, cement board, etc. Paper gypsum board is a board made from building gypsum as the main raw material, mixed with an appropriate amount of additives and fibers as the board core, and protected by specially made board paper. (Figure 5) Paper faced gypsum board has good porosity, with 40% of pores and good adsorption. Phase change materials can be easily absorbed by it. And paper gypsum board has the characteristics of light weight, sound insulation, heat insulation, strong processing performance, simple construction methods, and its price is relatively low [25].

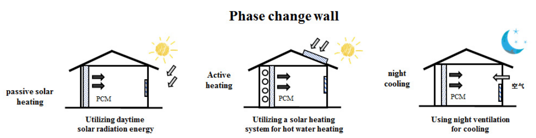

Fig 5. Application form of phase change heat storage building envelope structure [26]

4.1.2. Specific Application of Phase Change Energy Storage Wall Panels

Currently, in China, external wall insulation measures are widely used to maintain indoor cooling/heating loads for wall energy conservation [27]. Based on the design of building envelope structures, a certain thickness of insulation material is attached to the surface of the envelope structure, reducing energy loss and heat loss in the building, thereby achieving building energy efficiency.

At present, phase change materials can combine phase change materials without accumulated water or salts with original building materials, making them both load-bearing and energy storage properties. Cao Yanzhou and Sang Guochen from the School of Civil and Architectural Engineering at Xi'an University of Technology [28] A detailed study was conducted on the phase change materials used in walls. The two scholars first compared the wall structures of ordinary rooms and phase change rooms (Figure 6).

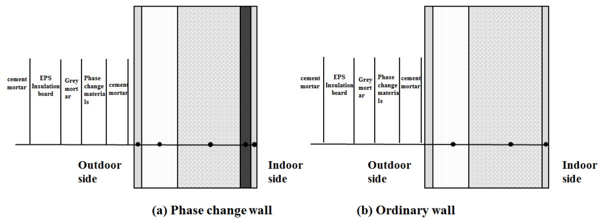

Fig 6. Phase change wall and ordinary wall comparison diagram [28]

4.1.3. Relevant Experiments on Phase Change Energy Storage Wall Panels

Ye Hai and Cheng Jun, School of Architecture and Urban Planning, Tongji University [29] Two scholars have found that when a small amount of phase change materials are applied to building walls, it can greatly increase the thermal storage capacity of the enclosure structure. The two conducted rigorous tests in the laboratory and comparison room to jointly determine the thermal storage effect of the phase change enclosure structure. After two days of real-time monitoring, it was finally found that during the operation of phase change materials, the temperature difference in the room was significantly reduced, and the time required for indoor air conditioning was significantly reduced. The thermal storage effect of phase change walls was continuously reflected. Subsequently, the two scholars conducted a more in-depth analysis of phase change materials using numerical simulations based on the climate conditions in the western region, mainly studying the effects of different types of phase change materials, changes in latent heat, thickness, and application directions on indoor temperature differences.

Ye Hai and Cheng Jun [29] Two scholars selected material walls with different phase transition temperatures for research. Due to different materials, the temperature inside the house exhibits different characteristics. Research has found that when the phase change temperature tm is 25 ℃ (close to the local annual average temperature), the indoor temperature fluctuation is the smallest, and the energy storage effect is the best at this time. As the latent heat of phase change increases, the fluctuation value (temperature difference) of indoor temperature shows a downward trend. But when the latent heat exceeds 200KJ/kg, its effect on the temperature difference decreases (Figure 7). Therefore, two scholars have come to an important conclusion: there is a critical value for the influence of latent heat of phase change materials on temperature difference.

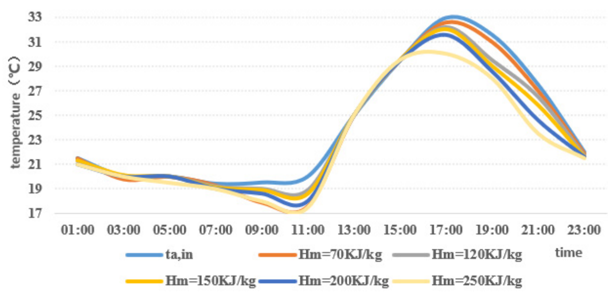

Fig 7. Indoor temperature change diagram of the wall body with different phase changes latent heat [29]

Subsequently, two scholars explored the impact of changing the thickness of phase change materials on indoor temperature differences. Research has found that when the wall thickness is 10mm, the indoor temperature fluctuation amplitude is the smallest, and the energy storage effect is the best at this time (Figure 8).

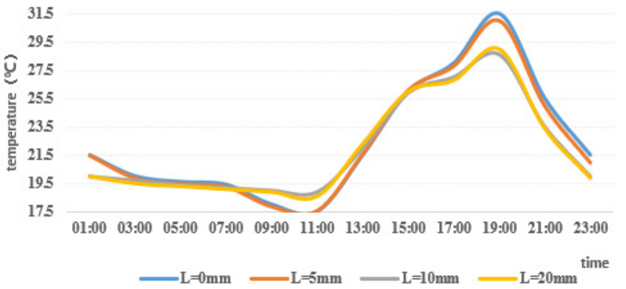

Fig 8. Indoor temperature change diagram of phase change materials of different thicknesses [29]

Finally, the two scholars used n, s, w, e to indicate the use of phase change materials in the north, south, west, and east walls, and g to indicate the use of phase change materials on the ground. They conducted research on the use of phase change materials only on one wall or only on the ground. The results showed that the use of phase change materials on any wall had a cooling effect on the temperature. Based on local conditions, the use of phase change materials on the north wall had the best effect (Figure 9).

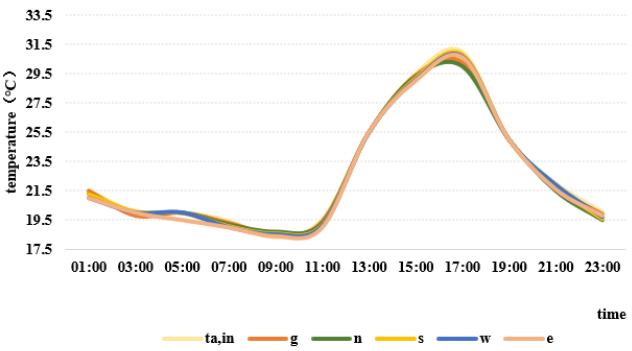

Fig 9. Indoor temperature change diagram using phase change materials on only the ground or only one wall [29]

Subsequently, two scholars also conducted research on the combination of ground and any wall, as well as the combination of any wall in pairs, and found that the combination of north wall and east wall (n-e), north wall and west wall (n-w) had the most obvious effect. Scholars have also conducted research on the combination of the ground and any two walls, as well as the use of phase change materials on any three walls, and found that the combination of the east, north, and west walls has the best effect, with a temperature reduction of nearly 2.12 ℃. Finally, scholars conducted research on the combination of the ground and any three sided walls, as well as the use of four sided walls together. They found that when four sided walls are used together with phase change materials, the effect is best, with a reduction of 2.34 ℃. Therefore, we believe that the best effect is achieved when using phase change materials together with four sided walls and the ground. Scholars have also conducted research and found that the effect of using four sided walls and the ground together is not as good as that of using only four sided walls.

4.1.4. Performance Optimization of Phase Change Energy Storage Wall Panels

The factors that affect the convective heat transfer of phase change wall panels are the internal surface convective heat transfer coefficient and heat transfer temperature difference. The heat transfer temperature difference is determined by the air temperature and wall surface temperature. The thermal properties and thickness of phase change wall panels can affect the temperature distribution inside the phase change wall panel, thus affecting surface heat flow changes. Especially, the thermal conductivity of phase change materials has a certain impact on the use of phase change wall panels [30]. The thermal conductivity of organic phase change materials containing fatty acids is relatively low. To improve their thermal conductivity, it is possible to consider adding substances with higher thermal conductivity such as metal grids, metal powders, and graphite powders.

Use equation (1-1) to determine the improvement in thermal conductivity of phase change materials after the addition of aluminum, copper, and graphite.

$$\lambda※ = \lambda_2\{1 - d_1 + d_1[3\lambda_1/(2\lambda_2 + \lambda_1)]\}/\{1 - d_1 + d_1[3\lambda_2/(2\lambda_2 + \lambda_1)]\} \quad (1)$$

$\lambda※$ —Thermal conductivity of mixed materials， W /(m·K);
λ_1 —— Thermal conductivity of discontinuous phases，W/（m·K）；
λ_2 ——Thermal conductivity of continuous phase，W/（m·K）；
d_1 ——Volume fraction of discontinuous phases。

Table 4. Improvement of thermal conductivity after mixing copper in phase change materials [30]

Percentage by weight added	5%	10%	15%	20%	25%	30%	35%
d(%)	0.50	1.10	1.77	2.50	3.35	4.30	5.40
λ_1[W/(m • K)]	398	398	398	398	398	398	398
λ_2[W/(m • K)]	0.143	0.143	0.143	0.143	0.143	0.143	0.143
λ※[W/(m·K)]	0.145	0.147	0.151	0.154	0.157	0.162	0.167

From Table 4, it can be seen that the thermal conductivity of the material mixed with copper has increased. When the weight percentage of copper accounts for 35% of the total weight, the thermal conductivity of the material has increased by 16%

Table 5. Improvement of thermal conductivity after mixing aluminum in the phase change material [30]

Percentage by weight added	5%	10%	15%	20%	25%	30%	35%
d(%)	0.02	0.04	0.059	0.08	0.11	0.14	0.17
λ_1[W/(m·K)]	237	237	237	237	237	237	237
λ_2[W/(m·K)]	0.143	0.143	0.143	0.143	0.143	0.143	0.143
λ※[W/(m·K)]	0.151	0.159	0.17	0.18	0.2	0.21	0.23

From Table 5, it can be seen that the thermal conductivity of the material mixed with aluminum also increases. Due to the relatively small density of aluminum, the volume ratio of aluminum and copper of the same mass makes its thermal conductivity higher than that of phase change materials mixed with copper powder. When the weight percentage of aluminum accounts for 35% of the total weight, the thermal conductivity of the material increases by 60%.

Table 6. Improvement of thermal conductivity after mixing graphite in phase change materials [30]

Percentage by weight added	5%	10%	15%	20%	25%	30%	35%
d(%)	0.02	0.05	0.079	0.11	0.15	0.19	0.24
λ_1[W/(m·K)]	129	129	129	129	129	129	129
λ_2[W/(m·K)]	0.143	0.143	0.143	0.143	0.143	0.143	0.143
λ※[W/(m·K)]	0.15	0.17	0.18	0.19	0.22	0.24	0.27

From Table 6, it can be seen that the thermal conductivity of mixed phase change materials is directly proportional to the amount of graphite added, and the improvement of thermal conductivity of phase change materials doped with graphite is better than that of phase change materials doped with copper and aluminum.

4.2. Application of Phase Change Materials in Floor Heating

The phase change energy storage electric floor heating system consists of an insulation layer, an electric heating layer, a phase change layer, an air layer, and a floor covering layer from bottom to top. At night, the electric heating layer heats the phase change layer, allowing the phase change material to melt and absorb heat; During the day, heating is stopped and the phase change material solidifies to release heat [31]. Electric floor heating is a heating technology that utilizes clean energy. Compared with other energy heating technologies, the thermal environment of a room is heated by a board, and the heat transfer model is simplified under some assumed conditions. It is found that the combination of phase change energy storage technology and electric floor heating technology promotes the utilization of electricity during low electricity consumption periods. Cao Yanzhou and Sang Guochen from the School of Civil Engineering and Architecture at Xi'an University of Technology [28] compared the structures of ordinary floors and phase change floors (Figure 10).

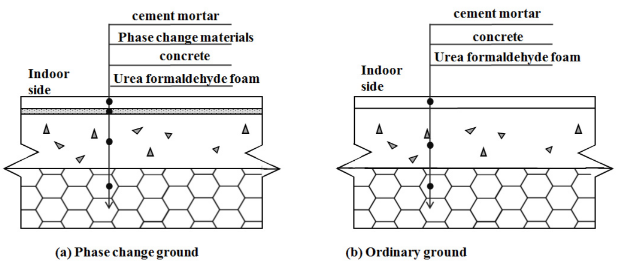

Fig 10. Phase change ground and ordinary ground comparison diagram [28]

4.2.1. Composition of Phase Change Energy Storage Flooring

The phase change energy storage electric floor heating and air supply system is composed of an air layer, a supply outlet, and a return outlet, which constitute the phase change energy storage electric floor heating and air supply system. The significance of the energy storage electric floor heating and air supply system is not only to establish an air layer between the phase change material layer and the floor covering layer, but also to introduce the popular concept of floor air supply. The floor covering layer is equipped with adjustable slow ventilation openings and small fans for air supply. This method not only has the advantages of passive heating, but also has the advantages of underfloor air supply [32].

4.2.2. Specific Application of Phase Change Energy Storage Floors

The phase change energy storage electric floor heating system applies phase change energy storage technology to floor heating, and adds phase change materials to the ordinary electric floor heating system. It utilizes the advantage of peak valley electricity price difference for heat storage and exchange. Designs like this can store abundant solar energy during the day and release it at night, causing indoor temperatures to fluctuate within a small range throughout the day, reducing people's time using air conditioning, and achieving energy-saving effects. (Figure 11) After the heating cable is energized during the low valley electricity period at night, it not only provides indoor heat, but also primarily heats the phase change material layer to melt and absorb heat; During non-low electricity periods, the cable stops heating and the phase change material solidifies to release heat, utilizing the heat stored at night to meet the heating needs of the room during the day. The system uses cheap low valley electricity at night, which not only achieves peak shifting and valley filling to save operating costs, but also provides a stable heating environment, reduces indoor temperature fluctuations, and improves thermal comfort [32].

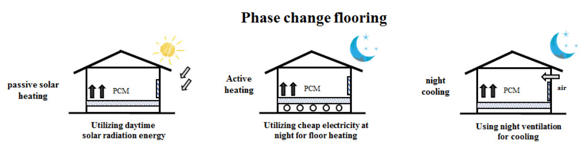

Fig 11. Application form of phase change heat storage building envelope structure [26]

4.2.3. Performance Optimization of Phase Change Energy Storage Flooring

The phase change energy storage electric floor heating and air supply system utilizes low-priced electricity to heat phase change materials and store heat energy at night, releasing heat during peak and normal periods, fully utilizing the difference in peak and valley electricity prices to meet the needs of room heating. On this basis, floor air supply can increase indoor temperature and improve room comfort. Scholars such as Feng Guoguo [32] conducted in-depth experimental research on this, considering that in the night power mode, the indoor temperature in the morning can meet the design needs, and the daytime is for outdoor work. The room air supply time is set at 16:00 to 22:00, and each working condition is tested continuously for 3 days, and a typical day is recorded and selected for analysis. By analyzing the temperature changes in indoor space under different conditions, the effect of "shifting peaks and filling valleys" is obtained.

Scholars such as Feng Guobiao and others [32] ultimately concluded that phase change energy storage electric floor heating systems can effectively achieve peak shifting and valley filling in night power mode. At night, phase change materials can store heat energy during low valley electric heating, while phase change materials can stably release heat during peak and normal periods. At the same time, floor air supply can accelerate the release of heat from phase change materials and increase the room temperature. In the absence of sunlight, floor air supply can increase the minimum temperature in the room from 14.4 ℃ to 15.2 ℃. In the presence of sunlight, floor air supply can increase the minimum temperature in the room from 14.9 ℃ to 15.8 ℃. It can also improve the efficiency of peak shifting and valley filling while basically meeting the requirements of indoor design temperature.

The phase change energy storage electric floor heating system can utilize cheap valley electricity to store heat energy and release heat during peak hours in the night power supply mode. However, the overall indoor temperature is still a bit low, and the heat released by phase change materials during the air supply period does not significantly increase the room temperature. The main reason for the analysis is that the poor insulation performance of the floor in the room results in a fast initial heat release rate of phase change materials. At the same time, the poor insulation performance of the room also affects the heat storage capacity of the room due to excessive heat dissipation. If the insulation of the room structure is strengthened or the amount of phase change materials is increased, the heat storage of phase change materials can be effectively increased, thereby releasing more heat in the air supply mode to increase the room temperature and meet comfort requirements.

4.3. Application of Phase Change Materials in Other Fields

In addition to walls and floors, phase change materials have also been continuously applied to interior decoration materials. Scholars such as Zhou Jianzhong [33] have found that in recent years, gypsum board has become the preferred choice for consumers in indoor decoration. Therefore, they processed and improved the original gypsum board preparation process by combining gypsum powder with phase change microcapsules to form phase change energy storage paper gypsum board after hydration under certain conditions. They immediately used digital imaging equipment, image processing software, and thermal conductivity testers to test it, and finally found that compared to ordinary gypsum board sample rooms, using phase change energy storage gypsum boards can reduce the indoor temperature by up to 4 °C in summer, and reduce the power consumption by 22.5% compared to ordinary paper gypsum board rooms.

Xie Shangqun et al. [34] developed a paraffin/expanded perlite composite phase change energy storage material and applied it to building mortar as a roof material. The measurement results showed that building roofs can not only weaken indoor and outdoor heat transfer and thermal conductivity, but also better reduce indoor temperature differences. Koschenz et al. [35] developed a phase change gypsum ceiling containing paraffin microcapsules and introduced a capillary cooling system into the ceiling to cool the phase change material, ensuring that it is in a fully solidified state before each thermal cycle, in order to fully utilize its thermal energy storage capacity.

5. Conclusion

In recent years, with the continuous enhancement of China's national strength and rapid social development, especially after the comprehensive victory of the national poverty alleviation campaign in 2020, the quality and level of people's lives have been increasingly improved. The residential building area required by the people is also increasing, and higher requirements have been put forward for the residential environment.

Phase change materials have been successfully applied in various fields due to their many advantages, and have played an indispensable role in building energy conservation, environmental protection, and other aspects. But currently, each phase change material has its own drawbacks, such as high production costs and low thermal conductivity. Due to China's late start in this field and some research technologies not yet mature, it is also constrained in some fields. I believe that with the continuous exploration of many scholars, phase change materials will definitely play a more important role in the practice of building energy conservation at the next time point.

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