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Review on phase change materials and application in building energy saving

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Abstract: Phase change materials (PCMs) can be used for thermal energy storage and temperature regulation during phase change, and have broad application prospects in energy-efficient use and energy saving. The compatibility between traditional phase change materials and building materials is too bad to combine in building energy conservation. Therefore, the new phase change materials have become a research focus in the field of phase change energy storage in buildings. In the paper, the research progress of phase change materials in recent years and the optimization and application of passive building energy-saving are reviewed.

1 Introduction

The present energy generation from renewable resources does not meet the current global demand for energy supply, which strongly encourages the researchers to switch to safer and cleaner energy usage like sustainable energy resources. Therefore, phase change energy storage technology opens a new window to investigate more on renewable energy resources to fulfill the thermal, electrical, and storage demands[1]. In the building trades, the phase change materials are gradually used as novel construction materials to conserve building energy. In the paper, the characteristics and the application of PCMs in active building energy efficiency were reviewed.

2 Characteristics of PCMs

Phase-change energy storage technology is based on PCMs for energy conversion and storage to cut down the energy demand during peak times. Theoretically, substances with suitable phase change temperature and large latent heat can be used as PCMs, however, it is necessary to comprehensively consider stability, supercooling, corrosiveness, safety, and price of PCMs [2]. PCMs selection criteria are presented in Table 1.

Table1. PCMs selection criteria [3].

Category	Properties	Criteria
Phase-change energy storage technology is based on PCMs for energy conversion and storage to cut down the energy demand during peak times.	phase change temperature	operated range
	thermal conductivity	high
	specific heat capacity	high
	thermal stability	high
	phase change equilibrium	high
	phase separability	low
	density	stable
kinetics properties	supercooling	low
	capitalization rate	high
chemical properties	reversibility	high
	stability	high
	corrosiveness	low
	toxicity/flammability/explosive	no
economics	capacity	high

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	cost	low
eco- friendly	separability	high
	recyclability	high
	contamination	low

The scale of temperature and latent heat in phase change is shown in Figure 1. It shows that phase change temperatures of paraffin waxes, water, and mixtures of water and salt are matched to the temperature range for building energy efficiency so that they are utilized as the most common types of PCMs. Different types of PCMs have different advantages [3-6].

(1) Organic PCMs: high scale of temperature in phase change, high phase transition consistency, with self-nucleation properties, no phase separation, high nucleation rate; high stability, non-hazardous, non-reactive and non-corrosive; high compatibility with conventional structural materials.

(2) Inorganic PCMs: High latent heat, high thermal conductivity, non-combustible, small density change (small volume change during phase change), easily accessible at low cost, eco-friendly.

(3) Eutectic PCMs: high scale of temperature in phase change, high consistency of phase transition, no phase separation.

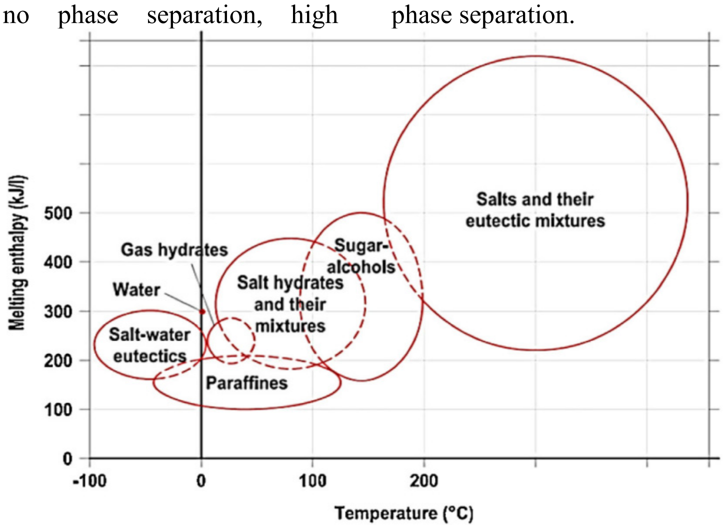

Fig 1. The scale of temperature and latent heat in phase change [7].

3 Passive Building application

Thermal energy storage for PCMs has been taken into considerations for the application in buildings with the gradual improvement of building energy consumption standards, and with the concepts and standards of passive buildings and near-zero energy buildings have been proposed. Building energy efficiency measures can be categorized as active or passive, where passive energy efficiency measures refer to a building's ability to resist, reduce or delay external disturbances such as reducing indoor and outdoor heat transfer by using envelope structures. Figure 2 shows the direction of the application of PCMs in active and passive heating systems [8]. Passive energy efficiency measures often combine solar energy with phase-change building materials, using solar energy storage to reduce the solar load and staggering use of solar energy.

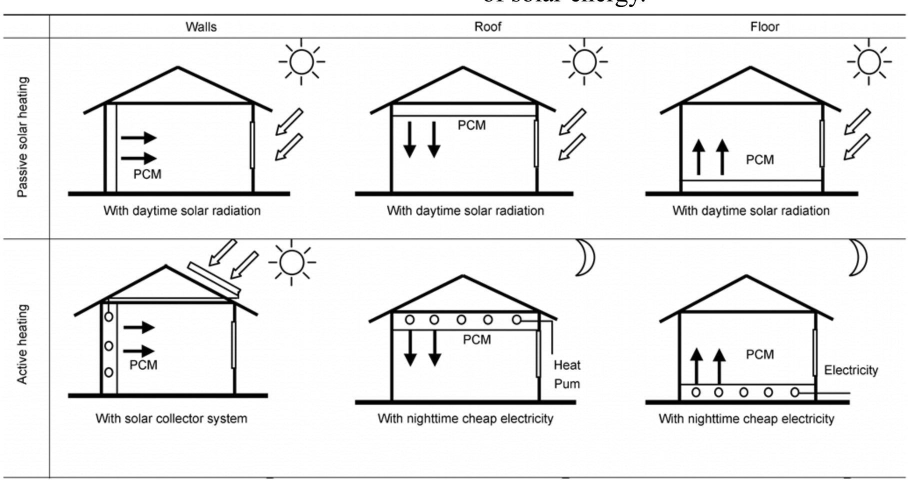

Fig 2. Radiant heating systems using PCMs [8]

Applying PCMs to walls, windows, roofs, and other building envelopes can change the building's heat load curve, reduce the peak, and even use the outdoor atmosphere as a cold or heat source to provide cooling or heating for the interior, which is an effective way to improve indoor environmental comfort and reduce energy consumption. For example, in winter, the PCM enveloped structure fully stores heat during the day and releases heat at night to bear all or part of the building's heat load at night. Another approach is to use building envelopes containing PCMs to store cold at night in summer to bear the building's cold load during the day. Such PCMs must be well integrated with the building materials, and the PCMs applicable to the building envelope are shown in table 2.

Table2. PCMs for Building

Phase change substance	Phase change temperature(°C)	Phase change latent heat(J/g)
C_{13}-C_{24}	22~24	189
C_{18}	28	244
dodecyl alcohol	17.5~22.3	188.8
pungent	16.5	153
sunflower acid	31.5	153
$KF\cdot 4H_2O$	18.8	231
$CaCl_2\cdot 6H_2O$	28	171
$NaSO_4\cdot 10H_2O$	32.4	254
butyl stearate	18~23	140
propyl palmitate	16~19	186

New organic composites in building PCMs draw attention currently. Zhang [9] prepared a composite PCM of sodium acetate and area and compared the positions of different PCMs in the external wall insulation based on the integrated discomfort level. The results show that to improve the thermal comfort of the interior, the PCM is preferably placed in the middle of the outer wall. Delcroix [10] used soybean oil and palm oil as PCMs with a phase change temperature of 23 °C. The phase change latent heat is 203 J/g, which is renewable and biodegradable. The researchers built the test house after adding the PCM to the wall material of the test house through the encapsulation technique, proving that the material is effective in reducing the energy consumption of the building.

Also, phase change building materials are often used in combination with solar energy, where solar radiation during the day is radiated either through collectors or directly in the PCM, providing heat for the building's night time heating. An enclosure consisting of a double-layer PCM was set up in the experimental room to absorb solar energy, as shown in Figure 3 [11]. The experimental study showed that this double-layer PCM increased the satisfaction of indoor thermal comfort conditions from 73% to 93% in a dry climate and from 63% to 75% in a semi-arid climate. The energy consumption for heating was reduced by 17.5% in a dry climate and 10.4% in the semi-arid climate. Zhang et al. [12] designed a solar heating system with a phase change thermal storage tank, and experiments show that the system can keep the indoor temperature above 20 °C under the minimum -10 °C outdoor conditions. Representative papers on PCMs of passive building were listed in Table 3.

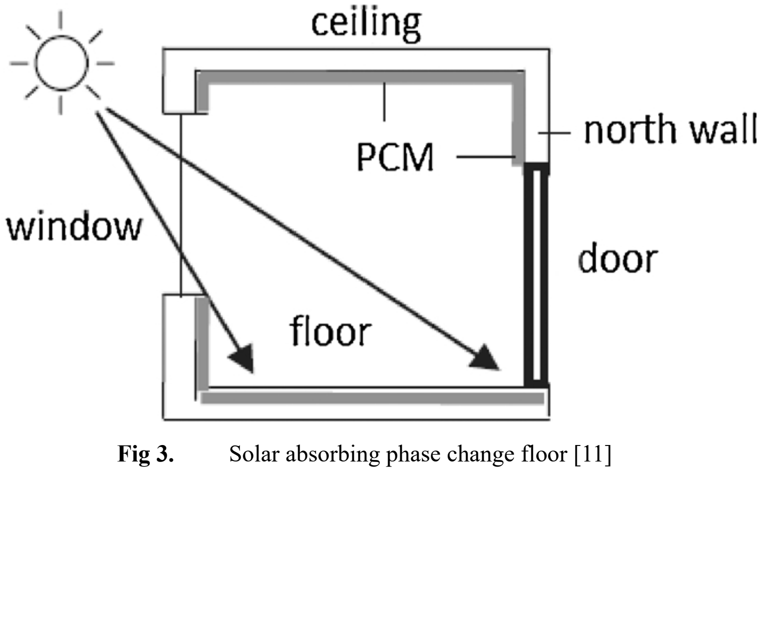

Fig 3. Solar absorbing phase change floor [11]

Table3. Studies on PCMs in active building energy conservation

Building Section	Author	PCMs	Time	Features
wall	[13]	Microcapsuled acrylic acid	2007	A new PCMs was studied, which was microencapsulated with acrylic acid and added into concrete to realize energy storage of the wall. The researchers used this concrete to build a hut in Lecter, Spain
	[14]	Acrylic acid	2012	Adding 25% acrylic acid phase change material into the plastering mortar, the latent heat of the phase change plastering mortar is 25 J/g, the phase change temperature is 23 °C to 25 °C, and the thermal conductivity is 0.3 W/m2· °C.
	[15]	Paraffin	2012	The invention relates to an embedded phase change clay brick, in which paraffin wax is wrapped and embedded into a hollow clay brick
	[16]	Fatty acid, paraffin and saline	2011	With glass brick as the shell material,
Window	[17]	Calcium chloride	2017	The heat storage properties of three kinds of phase change materials, fatty acid, paraffin and saline, were compared
	[18]	Paraffin with nano-particles	2020	The paraffin wax mixed with Al2O3, TiO2 and ZnO nanoparticles was added into the double-layer glass
Roof/Ceiling	[19]	Polyurethane with parafiin	2020	The influence of paraffin content of 15%, 25% and 35% on waterproofing and thermal stability of polyurethane roofing was studied
	[20]	Paraffin wax	2019	A wood-plastic board roofing material embedded with phase change material (paraffin wax) was developed
Floor	[21]	Eutectic fatty acids	2018	A floor made of a mixture of eutectic fatty acids as phase change materials

4 Conclusion

Current studies are mainly focused on the phase transition temperature and latent heat of phase transition of PCMs, with other thermophysical parameters less studied. The optimization of the overall properties of PCMs is the highest potential direction of further study. For instance, the organic PCMs have no subcooling and phase separation but with low thermal conductivity. The inorganic PCMs have strong thermal conductivity and heat storage capacity, and more studies will be needed on their suitable nucleating agent and anti-supercooling agent to optimize its phase-change performance. The phase transition temperature of eutectic PCMs can be controlled by changing the mass fraction of each component, and more studies will be needed on the improvement of their latent heat of phase change and specific heat capacity. Furthermore, to provide a viable means of improving energy efficiency, more focuses are also needed on the development of more simplified processes, reduced costs and promoted application to more occasions.

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