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Experimental study on thermal performance of phase change material passive and active combined using for building application in winter

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HIGHLIGHTS

- A novel phase change material wallboard has been fabricated.
- A self-made vacuum absorption roller was used to prepare phase change material wallboard.
- A heat accumulator was developed to connect with solar heating system.
- Heat accumulator with paraffin extended operation time of active solar system.
- Phase change material passive and active combination decreased energy consumption.

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ABSTRACT

Phase change material (PCM) used in buildings can increase building energy efficiency and decrease indoor temperature fluctuation. In this study, composite PCM was composed of paraffin and expanded perlite (EP) (60 wt%, 40 wt%) and was prepared through a self-made vacuum absorption roller. A phase change material wallboard (PCMW) was fabricated by the prepared composite PCM through the mould forming method. A plate-type heat accumulator (HAR) with embedded copper tubes was connected to a solar thermal heating system. HAR is fully filled with paraffin, which can store or release the heat gained by the solar thermal heating system. Therefore, PCM active and passive combination is realised through the PCMW incorporated in the building wall and the HAR connected to the solar thermal heating system in the same building. In order to analyze the performance of PCM active and passive combination, two same cubes were used to conduct a contrastive experimental study using different strategies under the winter conditions. The experimental result has indicated that (1) PCMW with melting point of 24.88 °C and latent heat of 59.68 J/g was incorporated in the walls, passively enhancing the thermal inertia of building envelope; (2) HAR with PCM extended the service period of solar thermal heating system; (3) PCM active and passive combination further enhanced the thermal performance of building envelope, indoor thermal comfort and building energy efficiency.

1. Introduction

Building energy consumption has been rapidly enhanced due to the increasing demand of indoor thermal comfort by the occupants. Recently, it was reported that buildings accounted for about 40% of the global energy consumption and contributed over 30% of the CO_2 emissions in the world [1]. For improving the building energy efficiency, many energy-saving technologies have been developed. As a thermal storage technology, PCM was widely researched in buildings, because it can store and release the heat during the solid-liquid phase changes [2]. Building applications of PCMs can possibly be divided into two categories - PCM passive system and PCM active system. PCM passive system refers to PCMs that are integrated into the building envelopes to increase the thermal mass [3], which is especially beneficial in lightweight building envelopes with low thermal inertia. PCM active system refers to the storage capability of PCMs is integrated into heating or cooling systems, to attain peak load reduction and electrical demand decrease [4].

For PCM passive system, PCM was generally incorporated into the wallboards, floors, roofs, windows, etc. The thermal inertia of the building envelope was enhanced by PCM [4,5]. The incorporation of PCM and building envelope can also increase indoor thermal comfort by smoothing the indoor temperature fluctuation with its thermal absorbing/releasing ability [6,7]. Among the researches about PCM

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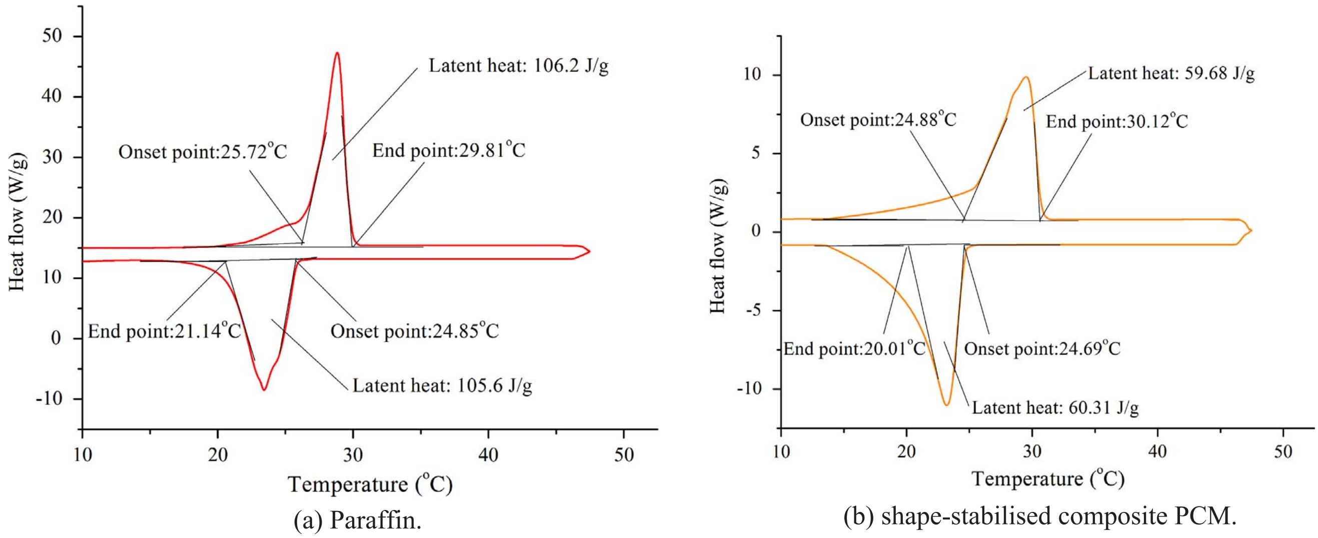

Fig. 1. DSC curves of Paraffin and shape-stabilised composite PCM.

passive system, the incorporation method with building materials is always important. The shape-stabilised PCM, a composite material consisting of PCM and supporting material, has attracted research interests, due to the advantages of keeping the shape during phase transition process, no need for container and large mass proportion of PCM in the total mass [8,9]. Generally, the supporting materials can encapsulate PCM into their internal micropores or three-dimensional structures. The commonly used inorganic supporting materials for building includes expanded graphite [10], expanded perlite [11], expanded vermiculite [12], etc. The most popular fabrication methods of shape-stabilised PCM with inorganic supporting materials are direct immersion and vacuum impregnation. Although direct immersion is simple and feasible, its retention capacity of supporting materials to store thermal energy is much lower than that of the vacuum impregnation [3]. The typical device for vacuum impregnation is composed of vacuum pump, suction flask, funnel and heater [13]. Most of the researches focused on the characterization and promotion of the properties, such as thermal property, morphology, chemical compatibility, thermal stability and thermal cycling stability [13–16]. However, the researches about building thermal performance for phase change material wallboard made of shape-stabilised PCM are few, especially under the winter condition.

A point in PCM passive application that should be paid attention to is the completeness of the PCM melting-freezing cycle. If PCM cannot fully melt or freeze, its capacity to store heat could be reduced [4,17]. The outdoor temperature variation influences for the melting-freezing cycle of PCM the most. The low outdoor temperature in winter is unfavourable for PCM passive system [18]. Thus, an active system is necessary to supply enough heat to complete the melting - freezing cycle of the PCMs and maintain the indoor temperature to a comfort level. Among the PCM active systems, PCMs are always combined with heat pump systems [19], heat recovery systems [20], floor radiation systems [21], etc. Peak load reduction or electrical demand decrease can be obtained by such systems [4,22]. Lv et al. [23,24] built PCM walls by gypsum board immersing fatty acids, and the PCM walls were combined with heating films. Results of real-room test indicated that this PCM wall can shift the building peak load in winter. Agyenim and Hewitt [19] used PCM (RT58) to store the heat generated by air source heat pump in off-peak electricity period. Another important application of PCM active system is to eliminate the discrepancy between the demand and supply side of solar energy [25,26]. Although solar energy is clean and non-polluting, it can't be used in the nighttime. Due to the energy storage ability, phase change materials can be used to store solar energy. In these solar heating supply systems, a PCM tank or bed is always necessary to store the solar thermal energy [25–28]. From the related researches, it can be proved that the system is energy efficient and effective. However, these studies often focused on the general building envelope, lacking for the combination of PCM passive system and active system. Therefore, a series of related experimental researches have been conducted in this study to validate the feasibility of the combination of PCM passive and active systems in the building.

A novel shape-stabilised composite PCM, which was composed of paraffin and EP, was prepared. An improved and more efficient vacuum adsorption method was used to fabricate enough amount of shape-stabilised PCMs for PCMW. The PCM passive system was attained by the incorporation of PCMW and building wall. Besides, HAR with an inside embedded heat exchanger copper tube was developed to be connected with a solar thermal heating system. The HAR was filled with paraffin and it was placed inside the room. One part of the collected solar heat was stored in the paraffin of the HAR, and the other part of heat was transferred to PCMW and indoor environment. The HAR and solar thermal heating system formed the PCM active system. To the authors' best knowledge, the integrated application of the PCMW, HAR and solar thermal heating system has never been studied. The combination of PCM passive and active systems can ensure most efficient utilization of solar thermal energy and enhance the thermal inertia of building, only consuming a little energy (pump power in solar thermal heating system).

2. Materials and methods

2.1. Raw material for PCMW

Paraffin is colourless and odourless and has good thermo-physical properties, such as high latent heat, negligible super-cooling and a suitable transition point [29]. Besides, the melting point can be selected according to different paraffin types. Due to the above reasons, paraffin with nominal melting point of 25 °C (purchased from Sinopec Nanyang Energy and Chemical Co., Ltd.) was selected as the phase change material in this study. Its phase change parameters are shown in Fig. 1(a), which were measured by the differential scanning calorimeter (DSC) (NETZSCH of STA409PC model) with a constant heating rate of 5 °C/min [12,30]. It can be found that the melting point, freezing point, melting heat, and freezing heat were 25.72 °C, 24.85 °C, 106.2 J/g, and 105.6 J/g, respectively. Expanded perlite with the density of 450 kg/m^3 and a specific surface area of 2.70 m^2/g (purchased from Xinyang Licheng Company) was used as the supporting material. Its thermal conductivity coefficient, heat storage coefficient, and specific heat