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Experimental study of phase change materials coupled solar thermal energy for building heating in winter

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Abstract: With the increasing of building consumption, the solar thermal energy has been seriously taken into account again. Because the phase change material (PCM) is characterized with huge energy storage, solar thermal energy can be converted into a continuous and stable energy resource and a higher indoor comfort is created. As a part of the coupled PCM-solar thermal collector system (CPSS), the integration of PCM and double-pipe heat exchanger (PDPE), was developed to couple PCM with solar thermal energy (PS) and experimented in a room. PDPEs encapsulating the mixture of capric acid and hexadecyl alcohol (CAHA) were installed in the floor and solar thermal collector was placed on the roof. Furthermore, several sequential experimental processes in winter were used for evaluating the applicability, energy saving ability and advantages of CPSS.

1. Introduction
The increasing users demand for more comfort condition has led to the dramatic increasing of building energy consumption [1], which has been exemplified in China, where the share of building energy consumption in social total energy consumption is 40% [2, 3]. During the past few years, the renewable energy has been taken seriously again under the tense international energy situation to avoid energy problems such as energy resources exhaustion, environment pollution and climate change [4]. Solar energy was a usual choice in architecture field nowadays, for three reasons: firstly, solar energy could be found in everywhere and used without exploitation and transportation, secondly, solar was a kind of the most clear energy, lastly, solar energy was huge, nearly 89 PW (1 PW=1015W) reaches the surface of earth [5]. However, solar energy was too instable and discontinuous to use in buildings directly, natural factors such as season changing, latitude and alternation of day and night as well as random weather factors such as cloudy and rain weather all had effect on using solar energy in buildings.

Energy storage technologies have been applied to make solar energy a continuous and stable energy resource. The phase change material (PCM), which could provide a high density of energy storage, has been selected and developed as the medium during the last 30 years [6]. The PCM ability to store lots of thermal energy in the melting process and release energy from it when under the freezing temperature, that made it an excellent method to improve the performance of solar thermal collector [7]. Besides, the PCM also could be used in buildings as a part of structures to smooth the temperature fluctuation and reduce the energy loss.

This study aims to study the performance of a new kind of building heating system with phase change materials coupled solar thermal energy. For most integration methods referred in literatures, the incompatibility of two technologies may cause some problems, such as leakage, poor thermal
conductivity and difficulties in build. Therefore, researchers of this study developed a new kind of PCM container which could be integrated with solar thermal collector system and building structures perfectly.

2. Presentation of the coupled PCM-solar thermal collector system

2.1 Phase change material

The tested room and system were designed to the cold region in North China, with hot summers and cold winters. In this region, the average temperature of the coldest month between 0℃ to 5℃ while the hottest month between 18℃ to 28℃, which was one of main standards for choosing phase change materials. Not only should the melting range be as large as possible for the long period of warm water in winter daytimes, but also the freezing range should be as small as possible for the short period of low temperature in summer nights. Because of melting/freezing point must be in the comfortable temperature range as well, lots of attempts were failed. Finally, researchers found a mixture of capric acid and hexadecyl alcohol (CAHA), which was prepared successfully. Figure 1 shows the DSC curves of CAHA.

2.2 Integration of PCM and double-pipe heat exchanger (PDPE)

The integration of PCM and double-pipe heat exchanger (PDPE), shown in figure 2, was composed of two concentric steel pipes: inner pipe and outer pipe. Inner pipe (DN25, 2000mm), was warm water path and 35mm high fins were equally distributed for intensifying heat transfer process. Furthermore, thread interfaces on both ends of inner pipe used to connect PDPE to system. Outer pipe (DN140, 1900mm) was shorter than inner and margins of both ends were weld with inner pipe by steel disc to create a cavity, where PCM sealed. In addition, a small piece of steel pipe (DN25, 50mm) inserted outer pipe through an eyelet, as the filling port of liquid PCM and the interface where an auto exhaust valve mounted.

2.3 The coupled PCM-solar thermal collector system

The coupled PCM-solar thermal collector system (CPSS) was composed of three units: solar thermal collector unit, PDPE unit and connection unit, as shown in figure 3. Researchers selected a group of vacuum tube collector (model: LPC58-1830, size: 2560×1935×158mm, specification: Φ58×1800mm×30, theoretical maximum heat efficiency: 57%) as the solar thermal collector unit. The total collector area is 4.8m² and the capacity of water more than 100L. PDPE unit consisted in fourteen PDPEs, side-to-side setup, installed in the floor. The thread interfaces on one ends of all inner pipes connected to water distributor and on other ends connected to water collector, integrated all PDPEs a parallel system. Meanwhile, the PDPE unit is prone to water imbalance, so a reverse return system adopted. Connection pipes of CPSS were made of galvanized steel, which connected the solar thermal collector unit, on the roof, and the PDPE unit, in the floor. Besides, connection unit also included a centrifugal water pump, a solenoid valve, a supplement tank, an ultrasonic heat meter, several
automatic exhaust steam valves, etc.

Figure 3. Structure of CPSS.

The CPSS was controlled by a differential temperature controller. The CPSS started to operate when the water temperature in collector tank reached 35℃, while stopped when air temperature in interior space reached 30℃ or the temperature difference between water temperature in indoor return pipe and air temperature in interior space is lower than 5℃. Stop prior to start.

2.4 Description of test room

The test room, as shown in figure 4, has a construction size of 3m×3m×3m. A plastic-steel door with a size of 1.8m×0.8m and window of 1.2m×1.2m were built in the northern wall and southern wall. The walls of 240mm thickness were composed of slag air bricks with a dimension of 390mm×240mm×190mm, which is wildly used in individual resident buildings in the cold region of North China. The roof was made of cast-in-situ concrete with a thickness of 150mm. Polystyrene board was installed on the outer sides of walls and roof, with a thickness of 45mm and 60mm, respectively, and crack-resistance mortar of 10mm thickness was plastered outside. By thermal calculation, heat transmission coefficient of walls and roof were 0.53W/m².K and 0.55 W/m².K, respectively. The test rooms were instrumented with thermocouples (T-type, copper-constantan, accuracy±0.2℃, 1mm diameter). The ultrasonic heat meter (JJRL-25) was installed in CPSS. Besides, a micro station (Onset HOBO H21-002) was installed on the roof of the room.

3. Results and discussion

3.1 Heating performance

Heating performance was mainly evaluated by two factors: indoor air temperature and heat input. As shown in figure 5, after a heat storage period about 5days, the indoor air temperature curve changed within the range of 18-26℃ all the time. This result illustrated the indoor thermal environment is quite comfortable and healthy, for indoor temperature is always in the comfort zone. Figure 6 contained two temperature curves for that the difference between the indoor air temperature and floor temperature determines the heat flux. During the stable operation from Feb.28 to Mar.9, the average heat flux provided into test room is 40.52 W/m².
3.2 PCM performance

The day Mar.4 was chosen as a typical day, which could be divided into 5 processes to analyze the performance of PCM. During Process I, the PCM solidified and released latent heat. During Process II, the PCM absorbed sensible heat form warm water and the temperature of PCM increased. During Process III, the PCM began to melt and store heat. During Process IV, the PCM had melt completely. During Process V, the temperature of PCM began to decrease due to the shutoff of warm water supplement. The Process V finished at the point that the temperature of PCM reach to its freezing point. According to the figure 7, the main PCM performance highlighted in two aspects: firstly, the PCM showed an excellent ability to make solar energy a continuous and stable energy resource, especially during the night, the PCM could provide a stable heat input about 40 W/m²; secondly, the PCM was good at smoothing the indoor air temperature fluctuation.
3.3 Energy utilization
As the only heat resource, solar energy determined the heat input, and the solar radiation determined the system energy utilization, as shown in figure 8. In this study, the average system energy utilization reached to 63.67% and the average solar energy utilization reached to 49.63%. Meanwhile, the CPSS operated with little power consumption, an average of 1.35 KWh per day, and the test room has on other heating equipment.

4. Conclusions
Several significance conclusions could be obtained from this study: firstly, the CPSS had a superior heat performance that about 40W/m² heat input was provided per hour during a long time and the indoor thermal environment was quite comfortable and healthy; secondly, the PCM and the PDPE shown an excellent ability to make solar energy a continuous and stable energy resource; thirdly, the CPSS operated in high energy utilization and little power consumption; finally, the CPSS and the PEDE performed much better in almost every aspect for creating a comfort indoor environment with little electric energy consumption, which showed a new way for using renewable energy in buildings, especially in vast rural areas.

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