



Two types of composite phase change panels containing a ternary hydrated salt mixture for use in building envelope and ventilation system

Wanchun Sun, Rui Huang, Ziyi Ling, Xiaoming Fang*, Zhengguo Zhang*

Key Laboratory of Enhanced Heat Transfer and Energy Conservation, The Ministry of Education, School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510640, China

ARTICLE INFO

Keywords:

Building energy consumption
Phase change material
Calcium chloride hexahydrate
Thermal conductivity
Ventilation system

ABSTRACT

Herein the co-integration of two composite phase change materials into building envelopes and ventilation systems was first explored for reducing indoor temperature fluctuation. Specifically, a ternary mixture consisting $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, NH_4Cl and $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$ was combined with expanded perlite and expanded graphite to prepare two composites with different thermal conductivities, followed by fabricating them into two kinds of panels. A test room composed of a main room and a ventilation system was constructed, in which the expanded perlite-based composite panels were placed at the insides of the four walls, floor and roof of the main room, while the other expanded graphite-based composite ones were incorporated into the ventilation system. It is shown that the ternary mixture consisting of 95 wt% $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ -4 wt% NH_4Cl -1 wt% $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$ exhibits a melting point of 23.46 °C, lower than that of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, making it more suitable for use in buildings. Its melting enthalpy is as high as 173.2 kJ/kg. The thermal conductivities of the expanded perlite- and expanded graphite-based composites have been measured to be 0.1170 and 9.720 W/(m·K), respectively. Compared with the room equipped with the expanded perlite-based composite panels at the envelopes, the one containing the two composite phase change panels at the envelopes and the ventilation system simultaneously exhibits a reduced indoor temperature fluctuation (22.29–28.69 °C) and a higher frequency of thermal comfort (78.3%). This work paves the way to the exploitation of hydrated salts as well as the applications of the phase change composites with different thermal conductivity in buildings envelopes and ventilation systems.

1. Introduction

Energy consumption in buildings accounts for a large proportion in the total energy use, and keeps increasing in recent years [1,2]. In buildings, most energy is used for space heating, ventilation and air-conditioning (HVAC) [3]. HVAC energy conservation is thus critical to decreasing building energy consumption [4]. Reducing indoor temperature fluctuation is an obviously effective way to decreasing the energy consumption for HVAC. This can be realized by increasing the thermal isolation ability and the heat capacity of building envelopes as well as adjusting the temperature of the air flowing into or out of buildings in ventilation systems.

Because of the ability to absorb or release large amount of latent heat during phase transitions [5], phase change materials (PCMs) have been widely applied in various fields such as waste heat recovery [6], peak power shifting [7], solar energy application [8], and so on. In recent years, researches on introducing PCMs into the building envelopes have attracted an increasingly interest [9]. It has been proven that

the PCMs incorporated into the walls [10], floors [11], roofs [12] or other envelopes [13] can function as reducing the indoor temperature fluctuation by improving the specific heat capacity of building envelopes [14]. This strategy is essential to the common lightweight buildings that only have the good insulation ability [15]. In our previous reports [16,17], a composite PCM (cPCM) composed of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ and expanded perlite (EP) was prepared, and the thermal performance of the test room equipped with the panels fabricated of the cPCM at the walls and/or roof was investigated. It has been found that, this cPCM based on the supporting material, EP, with a very low thermal conductivity, possessed both insulation property and heat storage capacity, showing great potentials in building envelope applications. It should be noticed that, those investigations concerning the applications of the PCMs in the building envelopes neglect the energy consumption originated from the variations on the temperatures of the air flowing into or out of buildings in ventilation systems. Note that ventilation systems are essential for modern buildings. PCMs have been also employed for decreasing the cooling (heating) energy demand by reducing the

* Corresponding authors.

E-mail addresses: cexmfang@scut.edu.cn (X. Fang), cezhang@scut.edu.cn (Z. Zhang).

Nomenclature			
<i>cPCM</i>	composite phase change material	<i>TM</i>	ternary mixture
<i>cPCP</i>	composite phase change panels	<i>VS</i>	ventilation system
<i>DSC</i>	differential scanning calorimeter	<i>XPS</i>	extruded polystyrene board
<i>EG</i>	expanded graphite	<i>XRD</i>	X-ray diffractometer
<i>EP</i>	expanded perlite	<i>Subscripts</i>	
<i>f</i>	temperature decrement factor	<i>max</i>	maximum
<i>FTC</i>	frequency of thermal comfort	<i>refer</i>	reference room
<i>HVAC</i>	space heating, ventilation and air-conditioning	<i>D</i>	dose not
<i>OSB</i>	oriented strand board	<i>test</i>	test room
<i>P</i>	a given period (24 h)	<i>Greek symbol</i>	
<i>PCM</i>	phase change material	φ	temperature lag
<i>PVC</i>	polyvinyl chloride	τ	time
<i>SEM</i>	scanning electron microscope		
<i>t</i>	temperature		

thermal flux from the fresh air to the indoor (or heat loss from the indoor air to the outdoor) [18], since the latent heat of the PCM can effectively heat or cool the air passing through the ventilation systems [19]. It has been revealed that the cold energy at night can be stored in the PCMs when the PCMs solidify at night [20] and retracted from them to cool the building during the melting at daytime [21]. Consequently, with an air-PCM heat exchange unit in the ventilation system, the building will benefit from a better thermal comfort and less energy use [22,23]. Hence, one can expect that, simultaneous applications of PCMs into building envelopes and ventilation systems will further reduce the indoor temperature fluctuations in buildings, thereby favoring the reduction in energy consumption. However, little work has been done on the simultaneous introduction of PCMs in building envelopes and ventilation systems yet. Moreover, it should be noted that the PCM applied into ventilation systems is required to have high thermal conductivity, which is different from the one used for building envelopes.

In the current work, a ternary mixture containing $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ was explored, in which NH_4Cl was added to reduce its melting point for making it more suitable for use in buildings [24], and $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$ acted as the nucleating agent to solve its super-cooling [25]. Then, the ternary mixture (TM) was combined with EP and expanded graphite (EG) to prepare two cPCMs with different thermal conductivities, followed by fabricating into two kinds of panels with different sizes. Finally, the TM/EP composite panels with low thermal conductivity were placed at the insides of the four walls, floor and roof of a test room, and the ones made of the TM/EG cPCM with high thermal conductivity were incorporated into the ventilation system above the room. The thermal performance of the test room equipped with both the TM/EP and TM/EG composite panels was evaluated and compared with that of the one equipped with only the TM/EP composite panels.

2. Experimental section

2.1. Materials

Anhydrous calcium chloride (CaCl_2 , AR), ammonium chloride (NH_4Cl , AR) and strontium chloride hexahydrate ($\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$, AR) were purchased from Ke Mi Ou Chemical Reagent Co., Ltd (Tianjin, China). EP (average diameter: 2–5 mm) was purchased from Henan Huitong Co., Ltd. EG (50 meshes) was purchased from Qingdao Hengrun Graphite Co, Ltd. Both of EP and EG were dried at 105 °C for 12 h to remove the adsorbed water on the surfaces.

2.2. Preparation and characterizations

2.2.1. Preparation of ternary mixture

Firstly, $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ was prepared by dissolving CaCl_2 in deionized

water. The mole ratio of CaCl_2 to deionized water was 1:6. Then, different contents of NH_4Cl (1–8 wt%) were added into the solution to obtain a series of binary mixtures ($\text{CaCl}_2 \cdot 6\text{H}_2\text{O} \cdot \text{NH}_4\text{Cl}$), followed by measuring their phase change characteristics.

After determining the composition of binary mixture, the nucleating agent $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$ was dissolved into this mixture at different contents (0.5 wt%, 0.8 wt%, 1 wt%, 1.2 wt%, 1.5 wt%), followed by stirring for 20 min. Based on the DSC results and the cooling curves, the composition of the ternary mixture (TM) was determined.

2.2.2. Preparation of the TM/EP cPCM

Refer to the vacuum impregnation method [26], the TM/EP cPCM was prepared by uniformly mixing TM and EP. At first, the TM was heated at 50 °C to obtain a liquid mixture. After that, 45 wt% of EP was added slowly into the liquid TM, followed by stirring for 20 min. Finally, the liquid TM was absorbed into the EP for 30 min under a vacuum pressure of 88.5 kPa. The obtained TM/EP cPCM was cooled at 5 °C to ensure that the TM had changed its phase from liquid to solid.

2.2.3. Preparation of the TM/EG cPCM

The melted TM was added into the given amount of EG under continuous stirring to prepare a cPCM, in which the mass fraction of EG was 12 wt%. When the absorption of TM completed, the TM/EG cPCM was placed into a sealed bag and placed in a refrigerator to complete the solidification of TM.

2.2.4. Characterization and measurements

The thermal properties of samples were measured by using a differential scanning calorimeter (DSC, DSC Q20, TA Instruments, URT100). Every sample (7–10 mg) was sealed in an alumina pan (Shanghai Dibo Experimental Equipment Co., Ltd.) and heated from –20 °C to 50 °C at a rate of 5 °C/min under a constant stream of nitrogen at a flow rate of 50 ml/min.

According to the T-history method [27], the cooling curves of samples were measured to determine their supercooling degree. Fig. 1 shows a schematic diagram of the experimental setup for measuring cooling curves. Before the measurement, 100 ± 0.20 g of the sample was weighed and placed in a glass test tube having a height of 120 mm, a diameter of 45 mm and a thickness of 2 mm. And then, the samples were put into a High-low alternate temperature humid heat test chamber (TH300, Shanghai Yiheng Scientific Instrument Co., Ltd.) to experience the heating-cooling process. During the experiments, the K type temperature-measuring thermocouple was used to measure the temperature of sample in real time. To reduce measuring error, the K type thermocouple was inserted into the center of the sample to avoid contact with the wall surface of the test tube. The heating-cooling process was set as follows: Firstly, the chamber was cooled from 25 °C

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