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EXPERIMENTAL STUDY ON THE DEMAND SHIFTING EFFECTS OF PCM INTEGRATED AIR-CONDITIONING DUCT

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Abstract. The proportion of electricity used for civil buildings is increasing, which intensifies the imbalance between the demand side and supply side of the grids and leads to a large decrement in grid efficiency and large energy losses. The phase change material (PCM) can be used to store numerous heat or cold for heating, ventilation, and air-conditioning (HVAC) systems for its phase change temperature range suitable for maintaining comfortable building thermal environment. Utilizing PCM for HVAC is an important way to mitigate fluctuations in the power consumption of buildings. This paper proposes a new type of air-conditioning duct combined with PCM. The demand shift effects of the PCM integrated air-conditioning duct is studied through experiments. The PCM material ingredients are designed according to the required phase change temperature range. The feasibility of PCM application in HVAC ducts is verified. The results show that air-conditioning duct combined with PCM can keep the indoor temperature in a comfortable range during the power peak load after shutting down chiller.

1. INTRODUCTION

Nowadays, the electricity consumption of civil buildings in the large cities of China accounts for nearly 40% [1]. With the increment of people's requirements for better living conditions, the demand for the high level thermal comfort of the indoor environment is increasingly getting higher, which causes the rapid increase of the energy consumption for the air conditioning in buildings. This situation aggravates the huge difference between peak and off-peak loads of electric grid and has brought about a series of problems, such as high investment cost of grid and power plant, low running efficiency during off-peak period, curtailment of renewable energy like wind and solar power, etc. Therefore, many scholars have proposed to use phase change materials (PCMs), which has high energy storage density, to store energy during electricity off-peak period and discharge the energy in peak time. By using PCMs, the comfort level of the indoor environment can be maintained without running chiller, so the peak load of building electric demand can be shaved and the demand response level of the power grid can be increased.

Numerous scholars have studied on the application of PCM in buildings and analyzed the heat transfer process and evaluated the performance. Zhong optimized the design of the ventilation times and the phase change temperature of PCM integrated with wall in the summer night and explored the effect of applying the phase change wall in different climate regions[2]. Lin proposed the summer overheating uncomfortableness as an index to evaluate the effect of phase change materials applications[3]. A theoretical model was established to optimize the phase change temperature of a room with phase change wallboard and night ventilation in different areas. Arkar and Medved used the latent heat storage

(LHTES) device integrated in the mechanical ventilation system, and proposed the encapsulated RT20 paraffin as the phase change material to achieve the free cooling of the building [4]. The thermal response model in TRNSYS was built to predict the outlet air temperature of the memory under the periodic changes of air temperature and defined operating conditions at the entrance environment. Pasupathy gathered the information from the earlier work on the developments of PCM's incorporation in building and concluded the selection methods of PCM for space heating and cooling[5].

This paper studies the demand shifting effects of the air-conditioning system combining phase change materials with air-conditioning duct through experiments. The fabrication method of the PCM air-conditioning duct is proposed. The effect of the PCM duct on the indoor temperature is verified by experiments and the possibility of the PCM air-conditioning duct to reduce the air conditioning load at the electricity peak time is verified.

2. PREPARATION AND TEST OF PCM

Through the literature review, the ingredients of the PCM for air-conditioning duct finally were decided as the mixture of capric acid and lauric acid (performance parameters shown in Table 1) for the following reasons. Dimaano and Escoto carried out experiments to test the properties of this C-L acid mixture in 1998[6]. They found that this mixture could be melted and solidified repeatedly. The volume of this PCM mixture was not changed obviously during the phase change process, and there was no supercooling phenomenon. The composition of the C-L acid mixture was not separated during the test which showed good chemical stability.

Table 1. Performance parameters of phase change materials

	Melting point (ºC)	mole fraction	molecular weight	mass fraction
Capric acid	>29	65%	172.2	61.5%
Lauric acid	>45	35%	200	38.5%

Since capric acid and lauric acid are both solid at room temperature, the containers containing capric acid need to be heated in water bath (at 50ºC). After the capric acid melted, the lauric acid was poured in and blended to make the mixture. The performance parameters of the PCM developed by the authors were measured using the test chamber (T-history chamber)[8], as shown in Figure 1.

Figure.1 Performance parameters measurement of the PCM developed by the authors

One tube of water was put into the chamber as the reference substance. The temperature of water and sample PCM are measured by the thermocouples. The measured temperature of air, water, and PCM are shown in Figure 2.

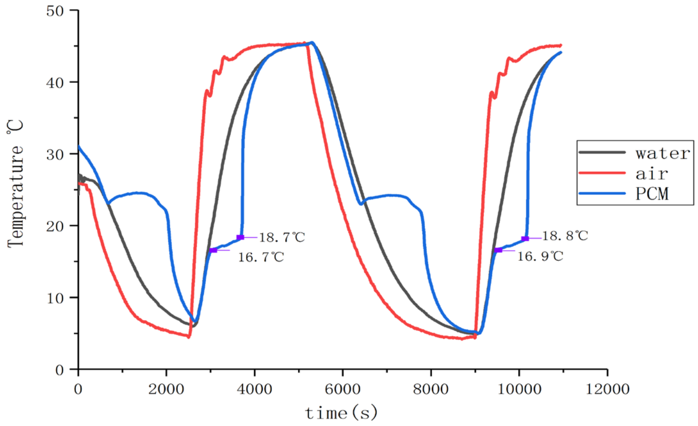

Figure 2. Temperature profile of air, water, and PCM in test chamber

The phase change temperature can be obtained during the temperature rising process, which is 16.7~18.8°C.Since the heat transfer coefficient of the tube outer wall and the air in the test chamber can be calculated according to the temperature change curve of the water, the latent heat H_m in the phase change process can also be obtained[7]. The formulas for calculating latent heat are as shown in Equation 1 to 3. The measured latent heat of the PCM is 148 kJ/kg.

$$H_m = \frac{m_w c_{p,w} + m_t c_{p,t}}{m_p} \frac{A}{A'} (T_r - T_{m1})$$

$$A = \int_{\tau_1}^{\tau_2} (T_a - T_M) d\tau$$

$$A' = \int_{\tau_3}^{\tau_4} (T_a - T_w) d\tau$$

Where m is mass, τ_1 and τ_2 present the time when PCM temperature reaches the melting temperatures of T_{m1} and T_{m2} , τ_3 and τ_4 present the time when water temperature reaches the solidifying temperatures of T_{m3} and T_{m4}.

3. EXPERIMENTAL TEST BED

A test bed was built in an ordinary office room to study the demand shift effects of an air-conditioning system with PCM duct. The PCM was capsulated and mounted into an air-conditioning duct. The structure of the air-conditioning duct with PCM is shown in Figure 3. The information of test bed and experiments is shown in Table 2. In order to observe the phase change progress, the air-conditioning duct was made with transparent panel. The PCM duct was installed at the outlet of a fan coil unit (FCU). The photo of the FCU mounted with the PCM duct is shown in Figure 4. In addition, fifteen thermocouples were set in the PCM duct at different locations to measure the temperature distribution. Nine of the thermocouples were used to measure the temperature of PCM at different height and others are used to measure the temperature of air. Because the duct is transparent, the phase change state of PCM can be observed conveniently.

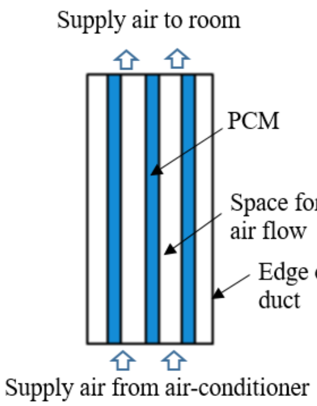

Figure 3(a). Structure of the PCM air-conditioning duct

Table 2. Information of experimental test bed

Location	Tsinghua University, Beijing
Floor area	16 m^2
Test duration	2018/06/12-2018/06/13
Computer	2
Person	1
PCM	16 kg

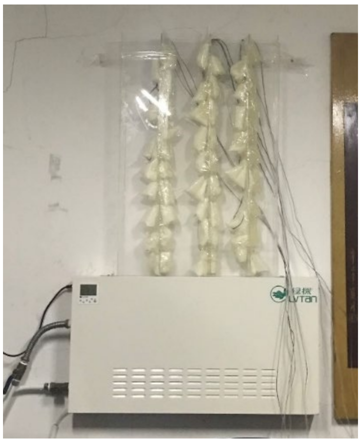

Figure 3(b). Experimental fan coil unit with the PCM duct at the outlet

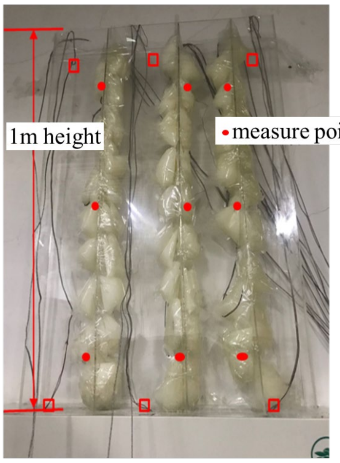

Figure 4. Temperature measuring points in PCM duct

4. Results and Discussions

A comparative experiment was carried out on the two days and the effects of PCM duct on maintaining the room temperature were studied. The ordinary experiment without PCM duct was conducted on June 12th 2018 and the experiment with PCM duct was conducted on June 13th 2018.

The outdoor temperatures on the ordinary experiment day of 12th June are shown in the left of Figure 5 and those on PCM experiment are shown in the right of Figure 5. The room temperatures after the chiller being shut down on the ordinary experiment day are shown in the left of Figure 6 and those on PCM experiment day are shown in the right of Figure 6.

The room temperature on ordinary experiment day rose from 23 to 26°C in one hour and it took half an hour that the room temperature rose from 25 to 26°C.

The room temperature on PCM experiment day rose far more slowly than that without PCM duct. It took 2.5 hours that the room temperature rose from 25 to 25.8°C after 2.5h. It can be seen from the experimental results that PCM duct has very large effect to maintain the indoor temperature stable in the comfortable range.

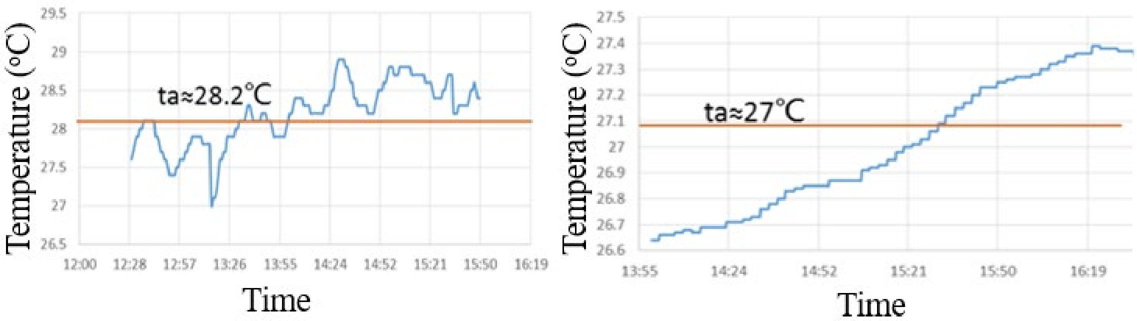

Figure 5. Outdoor temperatures on ordinary experiment day (left) and PCM experiment (right)

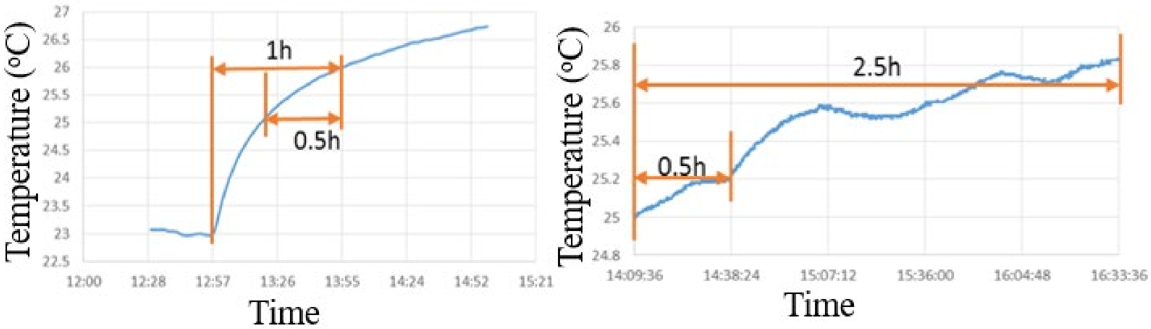

Figure 6. Measured indoor temperature on ordinary experiment day (left) and PCM experiment day (right)

The air temperature distribution in the PCM duct is shown in Figure 7. It can be seen that even after the chiller was shut down, the PCM had maintained the supply air at a low level of 16 to 22ºC for 3 hours (13:55-16:48). The PCM temperatures at nine measurement points are shown in Figure 8. Within the 3 hours from 13:55 to 16:48, the PCM temperatures kept at the temperature range of 14 to 18ºC. The low temperature of PCM was a very good cooling source to cool down the supply air down and to maintain room temperature within comfortable range.

The experiment results show the air-conditioning system equipped with PCM duct can effectively reduce the HVAC demands while maintain the room air temperature in the comfortable range for about 3 hours during the peak load period, which shows that the PCM duct is an effective way to achieve electricity demand shift while keeping the indoor thermal environment comfortable.

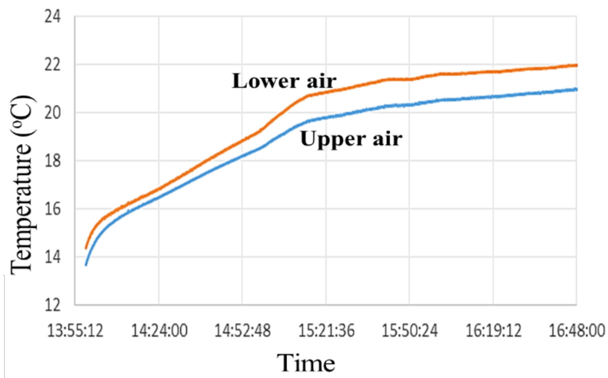

Figure 7. The temperature distribution of supply air

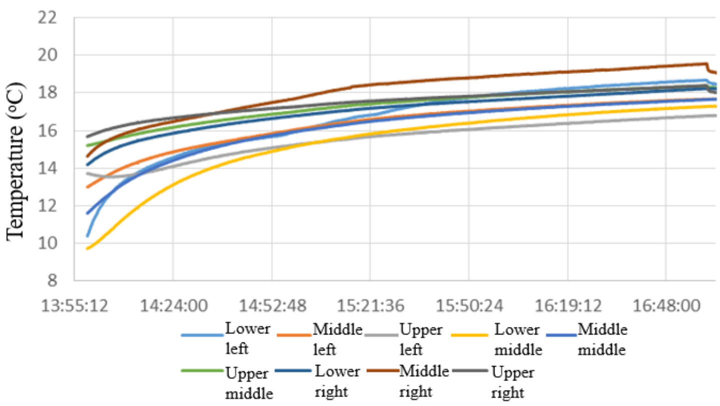

Figure 8. Temperature distribution of PCM in the air-conditioning duct

5. Conclusions

This paper proposes a structure of air-conditioning duct integrated with PCMs. A test bed of the air-conditioning system with PCM duct was built in an ordinary office room. Comparative experiments were conducted at the test bed between the air-conditioning system with and without PCM duct. The experiment results show that the room air temperature can rise by 3°C with 1 hour for the air-conditioning system without integrating with PCM after shutting down the chiller. While for the air-conditioning system equipped with PCM duct, it can maintain the room temperature rise less than 0.8°C for 2.5 hours. Roughly speaking, the capability of air-conditioning system with PCM duct can be nine times of the traditional air-conditioning system without PCMs. These results prove that PCM air-conditioning duct can be an effective way to help maintain the indoor thermal environment comfortable when shutting down chillers during peak load period to achieve demand shift.

Acknowledgement
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