Experimental analysis of PCM heat exchanger in ventilated window system

Yue Hu[*1], Per Kvols Heiselberg [1], Rui Guo [1]

1 Aalborg University, Aalborg, Denmark
**Corresponding email: hy@civil.aau.dk*

ABSTRACT

In this paper a new ventilated window with a PCM heat exchanger is proposed. In winter, the heat exchanger works as a solar collector to store heat for pre-heating of the ventilated air. In summer, it works in cooperate with night ventilation to pre-cool the ventilated air. In this work, the prototype of the heat exchanger is built and tested experimentally. The PCM heat capacity measured by differential scanning calorimetry DSC is used to help understand the phase change processes. The PCM temperature at different heights in both melting and freezing processes is measured. Moreover, the PCM temperature with different air flow rates is measured and compared. The results show that clear phase change is observed in both melting and freezing processes. The experiment with different air flow rates shows that the increase of air flow rate improves the heat exchange rate, but the improve rate is decreased gradually.

KEYWORDS

PCM, Ventilated window, Heat exchanger, Pre-cooling

1 INTRODUCTION

Thermal Energy Storage (TES) is efficient to be used in building applications for improving energy efficiency and energy conservation(*Heat and cold storage with PCM*, 2008). TES in buildings can be applied by sensible heat as well as latent heat. The latter has higher energy density with smaller volume (Iten, Liu and Shukla, 2016). Phase Change Material (PCM) used as TES has gained increasing interests in recent years. The latent heat capacity of PCM makes it store 5-14 times more thermal energy than sensible heat storage thermal mass (Sharma *et al.*, 2009). Moreover, the phase change occurs in a small temperature range with a large energy density (Johra and Heiselberg, 2017), which can minimize the temperature stratification in the space and prevent overheating of the surfaces (Pomianowski, Heiselberg and Zhang, 2013). The right PCM application has the advantages of peak hour shifting, building energy reduction and equipment size decreasing (Souayfane *et al.*, 2016). Another advantage is that it increases the thermal energy storage potential with small changes for existing buildings (Kośny, 2015).
The PCM applicable to buildings should be within human thermal comfort (20 ^{o}C -30 ^{o}C) if it interacts directly with the indoor environment. Moreover, it should be flame resistant and has long-term chemical stability (Kośny, 2015). Paraffin wax is most commonly used PCM for

buildings. It is non-corrosive, chemically stable with no sub-cooling effect, cheap with a high energy density (Johra and Heiselberg, 2017).

PCM in cooperation with free cooling technique has been used to provide cold air into the building in the demand time by means of ventilation (Souayfane, Fardoun and Biwole, 2016). (Darzi *et al.*, 2013) developed a PCM heat exchanger and investigated the influence of PCM plate thickness, air flow rate and inlet air temperature to the storage efficiency. They found out that there is a linear relationship between PCM plate thickness and melting time. (Lazaro *et al.*, 2009) tested two prototypes of PCM-air heat exchangers. The conclusion is that the design of heat exchanger is more important than the improving of PCM thermal conductivity.

PCM integrated with ventilation façade and window elements has the advantage of building space saving and easy design for architecture engineering in building design process. In this work, a ventilated window with a PCM heat exchanger is developed, as seen in Figure 1. It is designed to work both in winter and in summer. In winter daytime, it works as a solar collector which is charged by solar energy with PCM. The stored heat can be used to pre-heat the ventilated air when room ventilation is needed. In summer, ventilation is applied to discharge the PCM at night. The system is used to pre-cooling the ventilated air when room ventilation is needed.

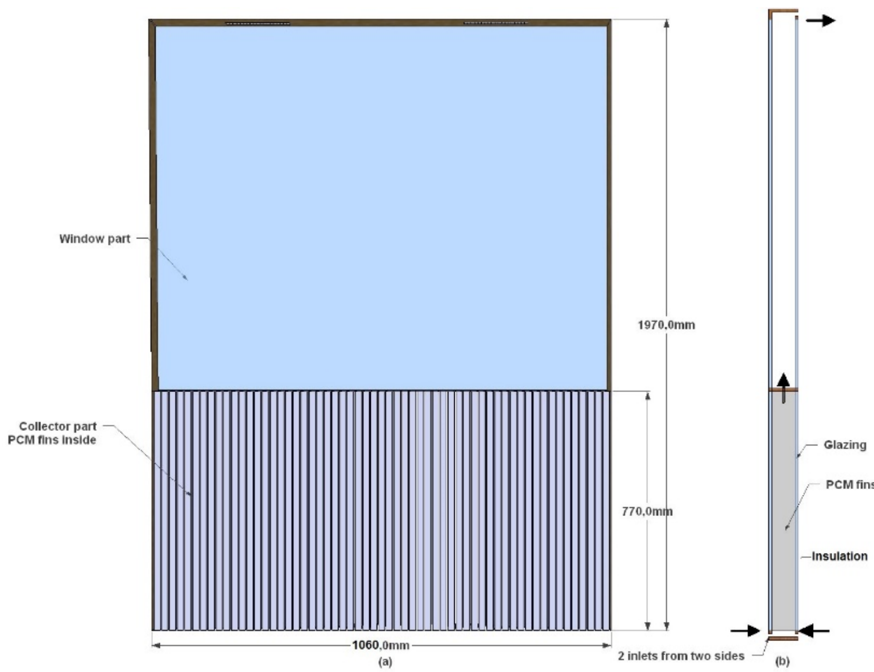

Figure 1: The sketch of the ventilated window with a PCM heat exchanger. Figure comes from (Hu and Heiselberg, 2018)

In this paper, a full-scale prototype of the PCM heat exchanger is built and tested. The thermal behavior of the PCM heat exchanger and its relationship to air flow rate is investigated.

2 EXPERIMENTAL SETUP

The PCM used in this work is paraffin wax 22, which change phase at around 22 ^{o} C. The PCM is sealed in fiber plate. The heat capacity of the PCM plate is done by DSC at heat rate 0.5 °C /min, which is shown in Figure 2.

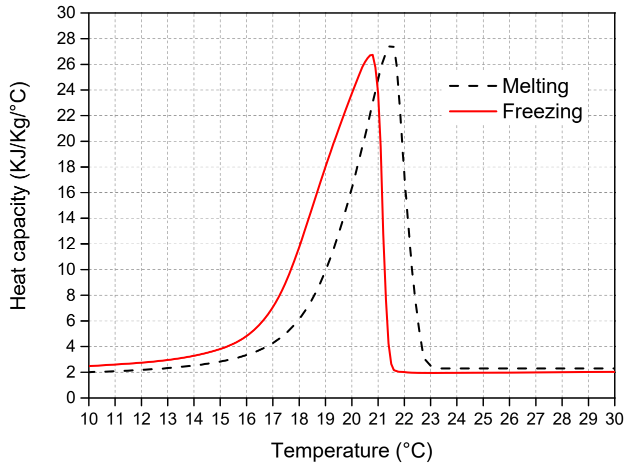

Figure 2: DSC measured heat capacity of the PCM plate in freezing and melting processes. Figure comes from (Hu and Heiselberg, 2018)

A prototype of the heat exchanger made by PCM plates is built and its thermal behavior is tested, as shown in Figure 1. The experimental setup is shown in Figure 3. It consists of a hot box and a cold box. A PID controller is used for keeping the temperature in the hot box at 28 ºC-30 ºC, and cold box 8 ºC -10 ºC. A fan is used to connect the hot box and cold box, and provide air flow inside the heat exchanger. Firstly the cold air from the cold box goes into the heat exchanger to freeze the PCM plates, then the fan direction is changed and the hot air from hotbox goes into the heat exchanger to melt the PCM plates. The flow rate of the fan is measured and controlled by the orifice plate. The temperature measurement is shown in Figure 4.

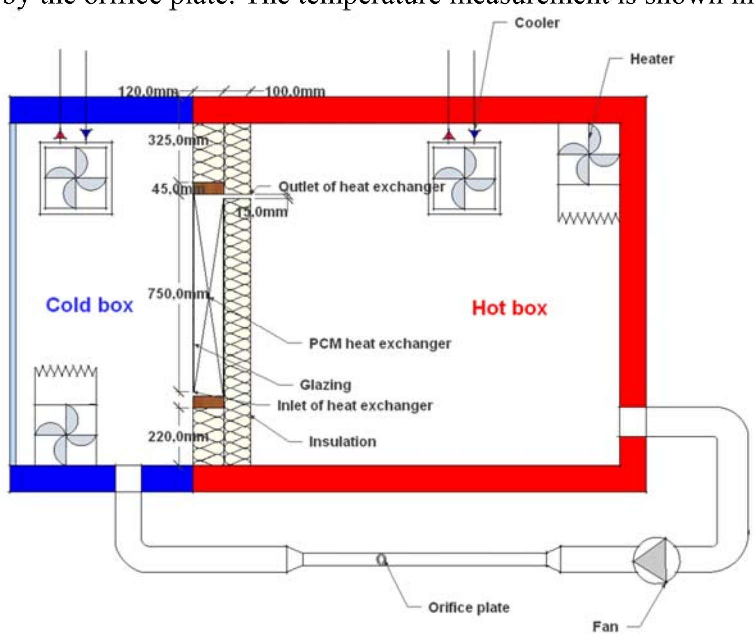

Figure 3: Experimental setup for the test of PCM heat exchanger prototype. Figure comes from (Hu and Heiselberg, 2018)

Figure 4: Setup of thermal couples in the heat exchanger

3 RESULTS

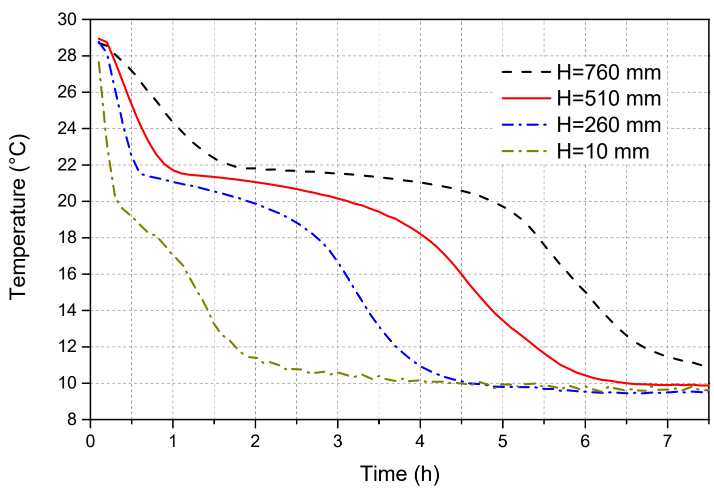

Figure 5: The temperature distributions along the height of one plate in the freezing process

Figure 5 shows the temperature distributions along the height of one PCM plate in the freezing process. The cold air goes into the heat exchanger from the bottom to the upper part driven by the fan. The PCM at the lower height freeze first, then is the higher part. The slope of temperature curves becomes small at 17 ºC -22 ºC, which is the temperature that the PCM goes through the freezing process. The temperature changes slowly in this process.

Figure 6 shows the temperature distributions along the height of one PCM plate in the melting process. The high-temperature air goes into the heat exchanger from the hotbox. The PCM at the higher part melts first than the PCM at the lower part. Similarly, the slop of temperature curves becomes small at 18 ºC -23 ºC, which is the temperature that the PCM goes through melting process.

The phase change observed in both melting and freezing processes are in accordance with the heat capacity curve shown in Figure 2.

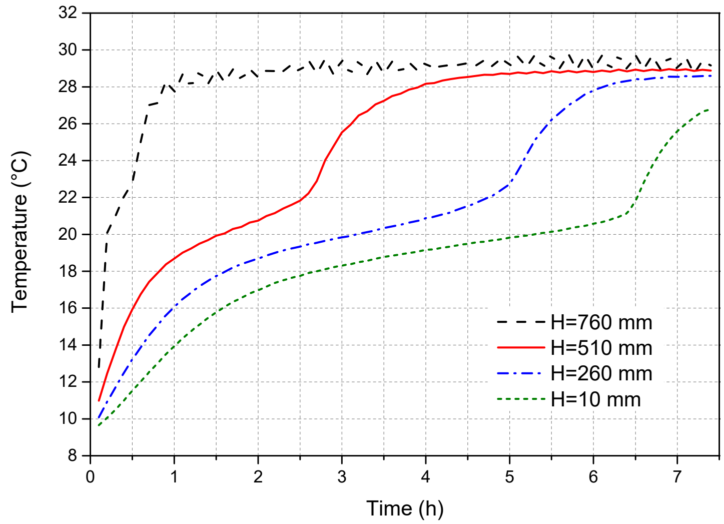

Figure 6: The temperature distributions along the height of one plate in the melting process

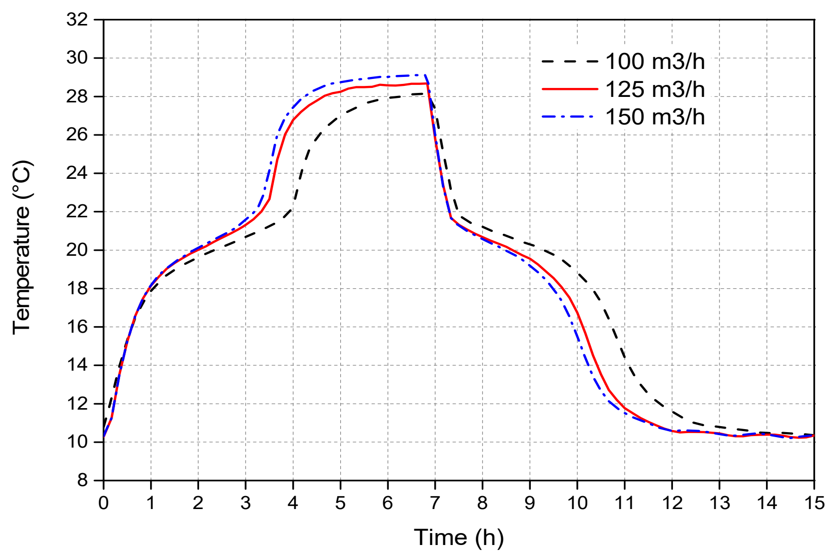

Figure 7: PCM temperature with different flow rates

Figure 7 shows the PCM temperature curves at the height of 260 mm in different air flow rates in both melting and freezing processes. The temperature curves show no big difference at the first beginning. The discrepancy shows when the phase change occurs. The temperature change rate is increasing as the flow rate increases, which indicates the improvement of the heat change rate. When the flow rate increases from 100 m^3/h to 125 m^3/h, the improvement of heat change rate is higher than that the flow rate increases from 125 m^3/h to 150 m^3/h. One explanation is that the temperature change rate is in relating to the conduction and convection heat transfer, and the convective heat transfer is the power function of air flow rate. Both melting and freezing processes shows the same trend.

4 CONCLUSIONS

A new ventilated window with a PCM heat exchanger is proposed in this paper. The system could work in both winter and summer. In winter, the heat exchanger works as a solar collector to store the heat from the sun. The heat is then be used to pre-heat the ventilated air. In summer night ventilation is operated to discharge the PCM at night. In the daytime the high-temperature outdoor air is ventilated through the PCM heat exchanger to charge it. The air is then pre-cooled and supplied to the indoor environment. With this system, the HVAC energy can be saved and the size of the HVAC could be diminished.

In this work, a prototype of the heat exchanger is built and its thermal behavior is tested in the lab. The PCM temperature in both the melting and the freezing processes are measured, as well as in different air flow rates. The main results are that clear phase change periods are found out in both processes. And the comparison with heat capacity measured by DSC shows that the heat rate 0.5 °C /min for the heat capacity measurement is accurate enough. The experiment with different flow rates show that the increase of flow rate improves heat exchange rate, but the increase rate is decreased. Future works include more measurement with different flow rates to analysis the relationship between flow rate and heat transfer.

5 ACKNOWLEDGMENTS

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