Experimental Study on Thermal Performance Improvement of Envelop Integrated with Phase Change Material in Air-conditioned Room

Yanru Li
College of Architecture and Environment, Sichuan University, China, 429506492@qq.com

Xi Meng
College of Architecture and Environment, Sichuan University, China, mengxihvac@163.com

Suo Wang
College of Architecture and Environment, Sichuan University, China, wangshuo748@qq.com

Enshen Long
longes2@163.com

Experimental Study on Thermal Performance Improvement of Envelop Integrated with Phase Change Material in Air-conditioned Room

Yanru Li[1], Xi Meng[1], Suo Wang[1], Enshen Long[1,2,]*

[1]College of Architecture and Environment, Sichuan University,
Chengdu, Sichuan Province, China
Contact Information (86-28-85401015, 86-28-85401015, longes2@163.com)

[2]Institute of Disaster Management and Reconstruction, Sichuan University-Hong Kong PolyU,
Chengdu, Sichuan Province, China
Contact Information (86-28-85401015, 86-28-85401015, longes2@163.com)

* Corresponding Author

ABSTRACT

Compared with the traditional building envelope, the thermal mass of building envelope integrated with phase change material was increased greatly, which would reduce the building energy consumption, improve thermal comfort, and shift the peak electricity load. Due to latent heat energy storage when phase changing, the wall integrated with PCM can release heat storage or cold storage to maintain the indoor thermal environment for a period of time after closing the air conditioning. This work presents the results of an experimental study of thermal performances of wall integrated with PCM and without PCM when the air condition runs continuously and intermittently. A building with these two kinds of walls is chosen and the inner surface temperature and heat flow are measured. The building have a domestic heat pump as a cooling system. The results show that the PCM can reduce the inner surface temperature 1℃, and reduce the inner surface heat flow about 40% when the air condition runs continuously. When the air condition runs intermittently by the working schedule, the PCM can also reduce the inner surface temperature 1℃, and the cold storage releasing time of wall integrated with PCM is 2 hours longer than wall without PCM. The PCM can improved the thermal performance of building envelop significantly.

1. INTRODUCTION

Electricity consumption and indoor thermal environment of a building be affected by building envelope thermal performance. One of the approaches for cutting down building energy consumption and enhancing indoor thermal environment is to integrate phase change material (PCM) into building envelope. Compared with the traditional building envelope, the thermal mass of building envelope integrated with phase change material was increased greatly, which would reduce the building energy consumption, improve thermal comfort, and shift the peak electricity load. When the temperature increasing, PCM absorbs heat while changing from solid to liquid. And when the temperature decreasing, PCM releases heat while changing from liquid to solid. Thermal energy can be absorbed and stored in PCM through a melting process. And compared with sensible heat storage system, latent heat storage system with PCM has higher energy storage density while requiring smaller masses and volumes of material. Wang et al. (2013) evaluated the thermal performance of ultrathin envelope integrated with PCMs by aid of numerical simulation for PCM heat conductivity coefficient, phase change heat, phase-transition temperature and PCM layer position. Feng and Liang (2006) built experimental rooms with phase change wall and ordinary wall, and used household air-condition for cooling. Results showed that the indoor air temperature of room with phase change wall was 1 or 2°C lower than that of room with ordinary wall. And heat flux was reduced by the phase change wall. In artificial climate laboratory, Kuznik and Virgone (2009) did experiments about the indoor thermal environment of PCM room and ordinary room in summer, winter and the transition season. Experimental results showed that the phase change wall could reduce the indoor temperature fluctuations. Behzadi and M. Faril (2011) did computer simulation about PCMs impregnated in building materials. The results showed that the use of PCMs can effectively reduce the daily fluctuations of indoor air temperatures and maintains it at the desired comfort level for a longer period of time. Yan et al (2012) studied the thermal properties of the PCM wall formed by different methods, and results showed that the surface temperature and heat flow through the PCM walls prepared by different methods are lower than that of traditional wall. Lei et al (2016) studied the energy performance of building envelopes integrated with PCMs for cooling load reduction in tropical climate through simulations. The results showed that PCM can effectively reduce heat gains through building envelopes throughout the whole year. Sun et al (2014) made selection of optimum phase transition temperature for the PCMs for the various climates using indoor and outdoor air temperature.

Existing studies show that PCM can improve indoor thermal environment of building. However, the applications of PCM wall in continuous air conditioned room and intermittent air conditioned room are different. This work presents the results of an experimental study of thermal performances of wall integrated with PCM and without PCM when the air condition runs continuously and intermittently. A building with these two kinds of walls is chosen and the inner surface temperature and heat flux are measured.

2. EXPERIMENTAL SET-UP

2.1 composite PCM wall

This paper test the thermal performances of wall integrated with PCM and without PCM. Figure 1 shows the cross-sectional schematic view of walls. The size of walls are both 600mm×600mm×260mm. For the composite PCM wall, its envelope consists of one layer of concrete plaster of 10mm, one layer of solid bricks of 220mm, one layer of PCM of 20mm and one layer of concrete plaster of 10mm. For the reference wall, its envelope consists of one layer of concrete plaster of 10mm, one layer of solid bricks of 240mm and one layer of concrete plaster of 10mm.And the physical properties of each layer material are shown in Table 1. The phase-transition temperature range of PCM is from 18°C to 26°C, which has phase change latent heat of 178.5kJ/kg.

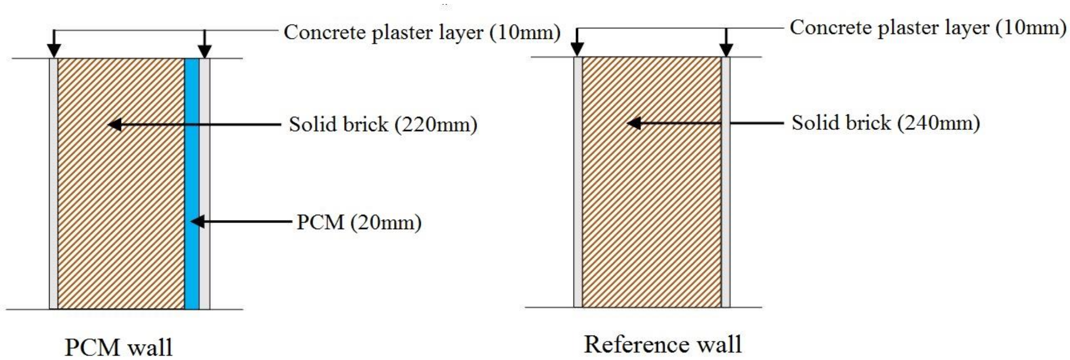

Figure 1: The cross-sectional schematic view of walls

Table 1: Physical properties of each layer material

Material	Density (kg/m^3)	Thermal conductivity (W/(m·K))	Specific heat capacity (kJ/kg·K)
Mortar	1406	0.3505	1050
Solid brick	1536	0.7505	523
PCM	1300	0.25(phase change), 0.5(solid or liquid)	1785

2.2 Experimental methodology

To study the building envelope thermal properties improvement by integrated with PCM, a dynamic testing experimental building are built in Sichuan University. From Figure 2 and Figure 3 we can see the experimental building consists of two rooms with the size of 3.5m (length) × 3.0m (width) ×2.2m (height). The north wall of Room 1 is a composite wall with a variety of wall types, and its structure is shown in Figure 4. The size of wall unit is 600mm×600mm×260mm. For the interface of wall unit, there is 80mm EPS to reduce the heat transfer between wall blocks and guarantee a one-dimensional heat transfer in the center of the wall unit. The PCM wall and reference wall studied in this paper are in the Room 1's north wall. And the indoor and outdoor environment of this two kinds of walls can be think the same. In order to achieve the continuous and intermittent air conditioning situation, a wall-mounted air condition (KFR-35gw/HFJ+3) is installed in the Room 1's south wall.

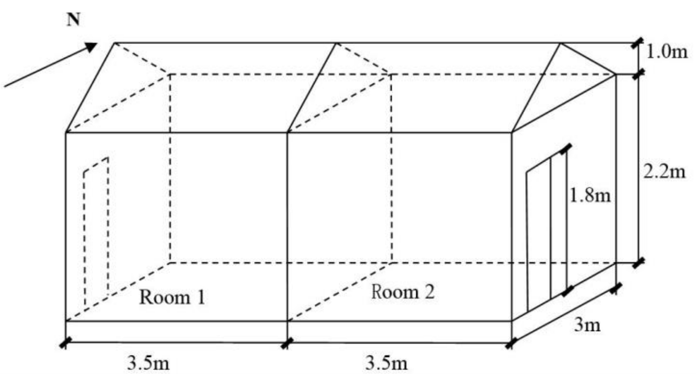

Figure 2: The experimental building

Figure 3: The appearance of the experimental building

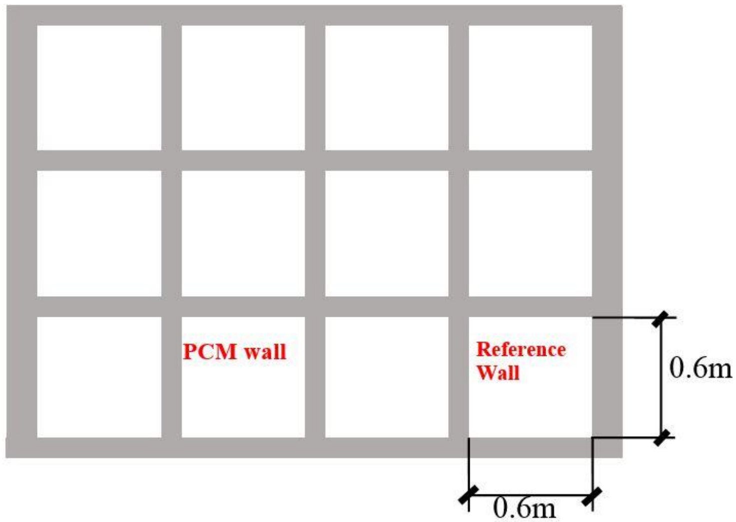

Figure 4: The structure of Room 1's north wall

The measured parameters in this experiment include indoor and outdoor air temperature, inner surface fluxes, inner surface temperatures and outside surface temperatures of PCM wall and reference wall, all of which are recorded by JTRG-II building thermal temperature automatic tester. To ensure the phase change process of PCM, the air condition temperature is set at 16℃ during the experiment.

3. RESULT AND DISCUSSION

3.1 The continuous air conditioning situation

The experiment of continuous air conditioning situation is from 16:00 June 2nd 2015 to 11:00 June 7th 2015. Figure 5 presents the variation of indoor and outdoor air temperature from June 4th to June 5th. During the experiment of continuous air conditioning situation, the minimum outdoor air temperature is 19.25℃, while the maximum is 36.10℃. The outdoor air temperature between day and night is 12-16℃. Though the air conditioning temperature is set at 16℃ during the experiment, the indoor air temperature is changing like sawtooth wave because the air condition lacking of frequency conversion and the power is larger. The compressor stops working when the indoor air temperature reaches the set temperature, and runs when the indoor air temperature is higher than the set temperature. The indoor air temperature in the continuous air conditioning situation changes between 13.4℃ to 17℃, and the average temperature of 15.4℃. As the outdoor air temperature fluctuations, the indoor air temperature presents a cyclical fluctuations while the air conditioning set temperature is invariable. The indoor air temperature increases significantly during 16:00-20:00 every day. And the indoor air temperature fluctuations delay 1 hour the outdoor air temperature because of the thermal inertia of building envelope.

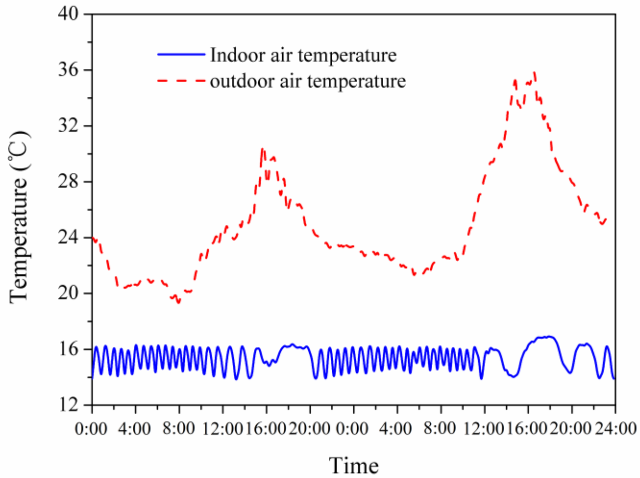

Figure 5: The variation of indoor and outdoor air temperature from June 4th to June 5th

Figure 6 presents the variation of inner surface temperature, and Figure 7 presents the variation of inner surface heat flux. During the experiment, the inner surface temperature of the PCM wall is lower than the reference wall. The average inner surface temperature of the PCM wall is 16.91℃, while it of the reference wall is 17.75℃. PCM can reduce the inner surface temperature about 1℃. In the situation of continuous air conditioning, the inner surface temperature fluctuation is different, and the inner surface temperature fluctuation of reference wall is large because its ability to resist the outdoor air temperature fluctuation is weak. Table 2 shows that the fluctuation amplitude of reference wall's inner surface temperature is 2.5℃, while it of PCM wall's is 1.9℃. With latent heat storage of PCM, the PCM wall can effectively decrease heat transfer through wall, and make heat attenuation and temperature delayed. Due to the test value of heat flux is negative, the inner surface heat flux of PCM wall is significantly lower than the reference wall, and the PCM wall has excellent energy saving potential. PCM can reduce the inner surface heat flux about 40%.

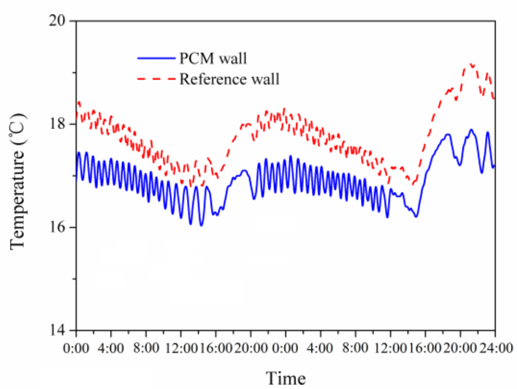

Figure 6: The inner surface temperature from June 4th to June 5th

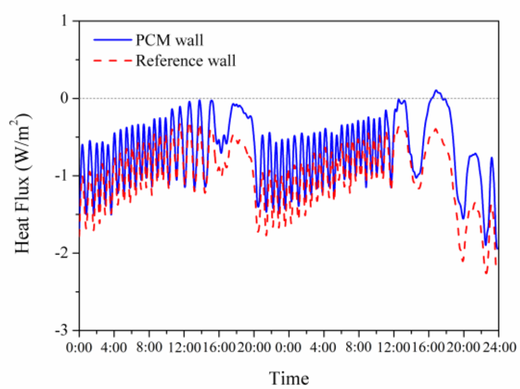

Figure 7: The inner surface heat flux from June 4th to June 5th

Table 2: The inner surface temperature fluctuations in continuous air conditioning situation

Wall type	Maximum value (℃)	Minimum value (℃)	Fluctuation amplitude (℃)
PCM wall	17.9	16.0	1.9
Reference wall	19.2	16.7	2.5

3.2 The intermittent air conditioning situation

The intermittent air conditioning refers to the residents regulate indoor thermal environment according to their own need. The intermittent operation mode is this paper refers to work schedule in office building, namely opening air condition during 8:00-18:00 and closing in other times.

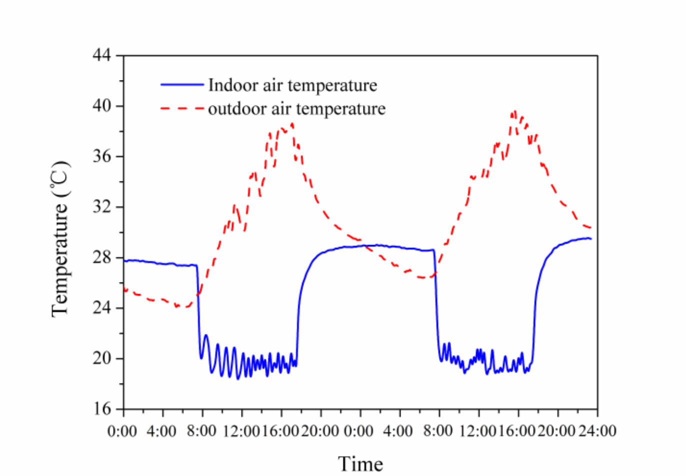

Figure 8: The variation of indoor and outdoor air temperature from July 31st to August 1st

The experiment of intermittent air conditioning situation is from July 31st to June 1st. Figure 8 presents the variation of indoor and outdoor air temperature during the experiment. The indoor air temperature changes significantly when the air conditioning operation mode changes. The indoor air temperature reduces quickly after opening the air condition, and goes to the first trough 20 minutes later. After 20 minutes, the indoor air temperature reduces slowly. The indoor air temperature is changing like sawtooth wave because the air condition lacking of frequency conversion and the power is larger. The indoor air temperature rises to normal in 1 hour after closing the air condition.

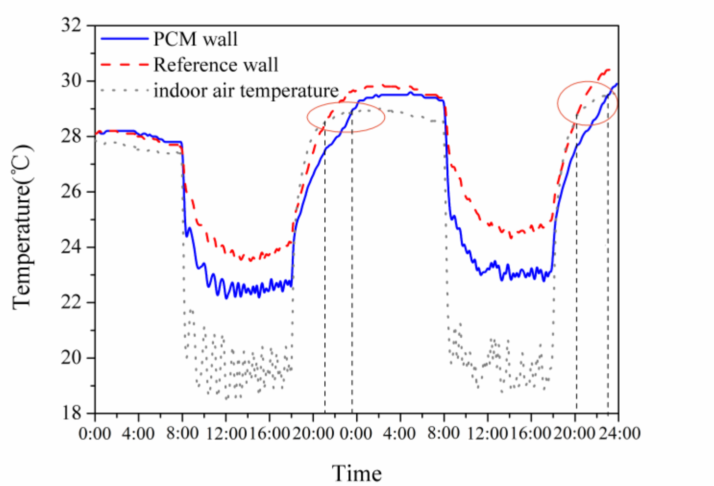

Figure 9: The inner surface temperature from July 31st to August 1st

It can be seen from Figure 9 that the inner surface temperatures reduce quickly and begin to cold storage after opening the air condition. The inner surface temperatures change quickly in the first 30 minutes since opening the air condition, and it begins to change slowly. The wall inner surface temperatures remain constant while the air condition has operated for 4 hours, which means the cold storage of walls is almost close to complete. The inner surface temperature of PCM wall is 1℃ lower than the reference wall during the operating time of the air condition. After turning off the air condition at 18:00, the inner surface temperatures increase rapidly. With rapid heating rate, the indoor air temperature rise to normal indoor temperature after 1 hour since the air condition turned off, and then the temperature remains constant. The indoor air temperature rises to higher than the inner surfaces temperature after 30 minutes since closing the air condition, which means the walls begin to release the cold stored during the air conditioning time. The inner surface temperature of the reference wall rises higher than the air temperature at around 20:00-21:00, and cold releasing is completed. The inner surface temperature of the PCM wall rises higher than the air temperature at around 23:00-23:30, and cold releasing is completed. When the temperature decreasing after opening the air condition, PCM absorb cold while changing liquid to solid. And when temperature increasing after closing the air condition, PCM release cold while changing solid to liquid. Due to the latent heat storage of PCM when phase changing, the cold storage by PCM wall is larger than the reference wall, so the cold storage releasing time of the PCM wall is 2 hours longer than the reference wall. However, the wall integrated with PCM can release heat storage or cold storage to maintain the indoor thermal environment for a period of time after closing the air conditioning.

4. CONCLUSION

This paper studied the thermal performance improvement of building envelope by PCM when air condition runs continuously and intermittently. The results show that the PCM can reduce the inner surface temperature 1℃, and reduce the inner surface heat flow about 40% when the air condition runs continuously. When the air condition runs intermittently by the working schedule, the PCM can also reduce the inner surface temperature 1℃, and the cold storage releasing time of wall integrated with PCM is 2 hours longer than wall without PCM. The PCM can improved the thermal performance of building envelop significantly.

REFERENCES

Wang J., Long E.S., Qin W., and Xu L. 2013. Ultrathin envelope thermal performance improvement of prefab house by integrating with phase change material. Energy and Buildings 67:210-216.

Feng G.H., and Liang R.B. 2006. Research on cool storage time of a phase change wallboard room in the summer. Proceedings of the Sixth International Conference for Enhanced Building Operation, Shenzhen, China, 36:133-136.

Kuznik F., and Virgone J. 2009. Experimental assessment of a phase change material for wall building use. *Applied Energy* 86:2038-2046.

Behzadi S., and Farid M.M. 2011. Experimental and numerical investigations on the effect of using phase change materials for energy conservation in residential buildings. *HVAC&R Research* 11(3):366-376.

Yan Q.Y., Huo R., and Li L.S. 2012. Experimental study on the thermal properties of the phase change material wall formed by different methods. *Solar Energy* 86:309-3102.

Lei J.W., Yang J.L., and Yang E.H. 2016. Energy performance of building envelopes integrated with phase change materials for cooling load reduction in tropical Singapore. *Applied Energy* 162:207-217.

Sun X.Q., Zhang Q., Medina M.A., and Lee K.O. 2014. Energy and economic analysis of a building enclosure outfitted with a phase change material board (PCMB). *Energy Conversion and Management* 83:73-78.

ACKNOWLEDGEMENT

This project is funded by the National Natural Science Foundation of China (No.51478280 and No.51178282)