

PAPER • OPEN ACCESS

Experimental Study on Heat Storage and Release Processes of Composite Phase Change Wall under Short Intermittent Heating Conditions

To cite this article: Yanru Li *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **556** 012029

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Experimental Study on Heat Storage and Release Processes of Composite Phase Change Wall under Short Intermittent Heating Conditions

Yanru Li¹, Jin Li¹, Luting Xu², Yang Ming¹, and Enshen Long^{1, 2, *}

¹College of Architecture and Environment, Sichuan University, Chengdu, China

²Institute of Disaster Management and Reconstruction, Sichuan University-Hong Kong PolyU, China.

E-mail: longes2@163.com

Abstract: During intermittent heating, the short intermittent conditions are common in meeting rooms of office buildings and school classrooms. The thermal process of building envelope has coupling effects on the indoor thermal environment in the frequent start-stop of heating equipment. This paper integrated phase change materials (PCMs) with building envelope to improve its thermal performance. Measurements were carried out to study the dynamic thermal process of composite phase change wall (composite-PCW) in case 1 (heating 1h + suspension 1h) and case 2 (heating 2h + suspension 2h). Results showed that: 1) the indoor air temperature fluctuations were around 14°C and 18°C respectively for case 1 and case 2 when the indoor thermal processes reached relatively stable. 2) The heat storage of composite-PCW could maintain the inner surface temperature relatively constant, so that the inner surface temperature fluctuations were only 5°C and 6°C respectively for case 1 and case 2. 3) The heat storage utilization rates of the last cycles were 5.08% and 14.86% for case 1 and case 2. Thus, the heat transferred into the wall during the heating period was stored inside the wall to improve the indoor thermal environment by rational use to maintain the inner surface temperature during the cooling-down period.

Keywords: Phase change materials; intermittent heating; heat storage; energy efficiency

1. Introduction

The indoor thermal environment in the intermittent heating process is different from that of continuous heating because of the frequent start-stop of the heating equipment, and the thermal process of building envelope has coupling effects on the indoor thermal environment [1]. Tsilingiris et al. [2] and Barrios et al. [3] studied the heat loss of different wall structures during intermittent heating. Wang et al. [4] investigated the floor heat storage and release during an intermittent in-slab floor heating process.

The thermal inertia of building envelope can affect the indoor environment variations [5], and the rational use of building heat storage and release processes help improve the indoor thermal environment. Ogoli et al [6] found that the wall constructed by heavy materials could reduce the indoor air temperature effectively. Cheng et al [7] comprehensively analyzed the effects of different building heat storage materials, different surface colours of exterior wall and different orientations on indoor temperature. During the intermittent heating process, the building energy consumption can be reduced through using building heat storage to optimal match the heating equipment operation.

Phase change materials (PCMs) are the ideal material for improving the heat capacity of building envelope due to the high thermal inertia in a relatively small temperature range [8]. Compared with the traditional building envelope, the building envelope integrated with PCMs is able to save energy consumption, improve the indoor thermal environment and transfer the electricity peak [9-10]. Zhang



et al. [11] found that the phase change wall could save the building energy consumption through increasing the fusion heat, reducing the thermal conductivity and selecting appropriate phase transition temperature. Castell [12] did experiments on two kinds of building envelope integrated with different PCMs. The results showed that the PCMs reduced the air conditioning energy consumption by 15% in summer. During intermittent heating, the indoor air temperature changes severely when the heating is on/off, so that the phase changing process of PCMs in the building envelope is more obvious when indoor air temperature changes. Wang et al. [13] found that the phase change wall could reduce the heating load by 10-30% in the intermittent heating operation, and the PCMs could reduce 9-27% of the internal surface heat loss after turning off the heating equipment. However, that paper divided the intermittent heating process into the heating process and the cooling-down process, which neglects the lasting effect of building envelope heat storage on the indoor thermal environment and the heating energy consumption.

Therefore, the influence of building envelope thermal process on indoor thermal environment is different under different intermittent heating conditions [14]. Because the short-term use of space in office buildings and schools, the heating equipment starts and stops frequently. Thus, the heating time and heating energy consumption is able to be reduced through using the building envelope heat storage and release processes to improve the indoor thermal environment. In this paper, PCMs are integrated to the inner side of wall to realize the wall energy saving during intermittent heating. Measurements were carried out to study the dynamic thermal process of the composite phase change wall (composite-PCW) under two short intermittent heating conditions. And the energy efficiency and indoor thermal environment improvement were investigated. This work provides theoretical support for the application of composite-PCW in intermittent heated buildings.

2. Experimental set-up

The experiment was carried out in the wall dynamic test building in Sichuan University (Figure 1(a)). The composite-PCW with size of 600mm×600mm×260mm consists of one layer of cement mortar of 20mm, one layer of PCMs of 20mm, one layer of foamed concrete of 200mm and one layer of cement mortar of 20mm from the inner side to outer side, and the schematic structures are presented in Figure 1(b). Table 1 shows the physical properties of each layer of material, and the phase-transition temperature range of the PCMs is from 18°C to 26°C, which has phase change latent heat of 178.5kJ/kg.

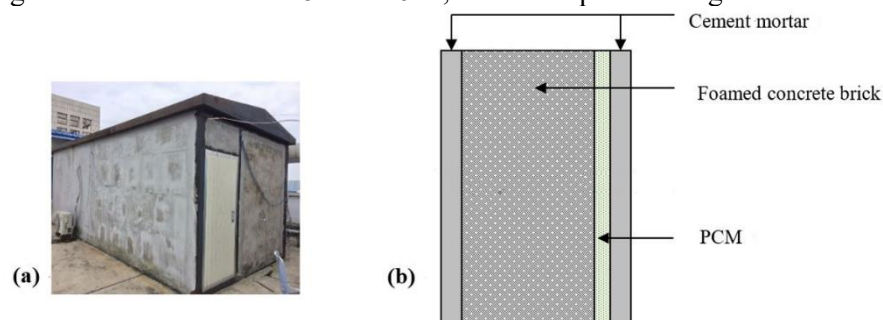


Figure 1. The experimental system ((a) the experiment test building; (b) The schematic structures of the composite-PCW).

Table 1. Physical properties of each layer.

Material	Density (kg/m ³)	Thermal conductivity (W/(m·°C))	Specific heat (kJ/kg·°C)
Cement mortar	1406	0.3505	1.05
Foamed concrete brick	500	0.1631	1.05
PCMs	1300	0.25(liquid), 0.5(solid)	1.785

T-type thermocouples with accuracy of $\pm 0.5^{\circ}\text{C}$ and heat flux meters with accuracy of 5% were selected, and all measurement data were recorded by a JTRG-II building thermal temperature automatic tester. Two short intermittent heating conditions were designed: a) case 1: heating 1h + suspension 1h, b) case 2: heating 2h + suspension 2h, which is shown in Figure 2. The measurements of case 1 and case

2 were carried out on 20th and 22th January 2016, and the first heating operation cycles both began at 9:00. The temperature and heat flux of the composite-PCW were measured. The heating thermostat setting was adjust to 30°C for winter space heating to ensure the phase change of PCMs.

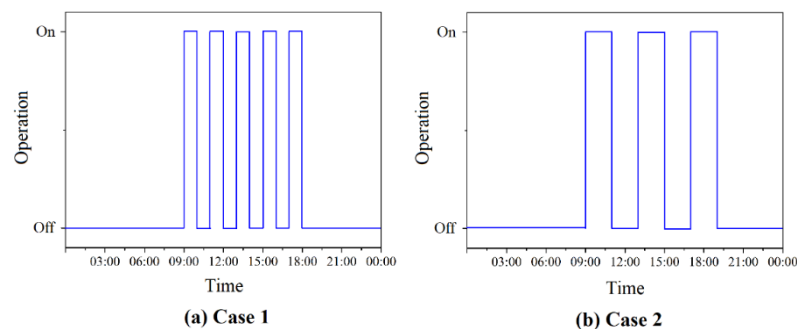


Figure 2. The short intermittent heating conditions.

3. Results and Discussion

3.1. Case 1: heating 1h + suspension 1h

Figure 3 presents the variations of the indoor and outdoor air temperatures in case 1. During the test period, the outdoor air temperature changed between 6.5–8.5°C. The indoor air temperature changed greatly with the heating equipment operation process in the five heating operation cycles. In the first operation cycle, the indoor air temperature was only around 11°C before heating, and rose to 29.95°C rapidly after heating for 1 hour while decreased to 14.62°C after stopping heating. Then the dynamic thermal response of the indoor air was accelerated because of the increasing heat storage of the room. The indoor air temperature changing rate increased after heating, and the minimum indoor air temperature of each cycle rose gradually when the heating was stopped. For the last four operation cycles, the indoor air temperature rose to around 31°C in the 1 hour heating process, and decreased to around 17°C in the 1 hour cooling-down process. The last heating process ended at 18:00, and the indoor air temperature decreased rapidly. The indoor air temperature was above 16°C while the cooling rate gradually decreased. After 2 hours cooling-down process (after 20:00), the cooling rate increased, and the indoor air temperature decreased to 9.8°C. Excepting for the first operation cycle, the indoor air temperature was always higher than 15°C during the intermittent heating, and the fluctuation range was about 14°C.

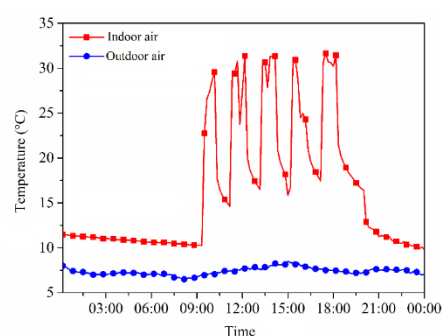


Figure 3. The variations of indoor and outdoor air temperatures in case 1.

Figure 4(a) presents the variation of surface temperatures of the composite-PCW in case 1. The variation of outer surface temperature was similar to the outdoor air temperature. And the outer surface temperature did not increase in the heating process of the five operation cycles, which indicates that the heat loss to outdoor through wall was less due to the wall thermal inertia. During the test period, the inner surface temperature of the composite-PCW changed greatly with the variation of indoor air temperature. And the wall stored heat during 1 hour heating process of each cycle to maintain the inner surface temperature constant, leading to the increase of the inner surface temperature. Thus, the inner surface temperature was always higher than 16°C in the last three cycles, and the temperature fluctuation

was only about 5°C. Figure 4(b) shows the variation of the inner surface heat flux. The value of inner surface heat flux remained around 0 from 0:00 to 9:00, indicating that there was no heat transfer between the indoor air and the composite-PCW. After starting heating at 9:00, the heat flux of the inner surface increased rapidly, which means that the heat was transferred into the wall. After stopping heating, the inner surface heat flux decreased to 0 because the indoor air temperature decreasing. In the following four operation cycles, the heat transferred into the composite-PCW decreased gradually during the heating process because the wall heat storage increased with the intermittent heating operation, so the increase of the inner surface heat flux during the heating processes gradually decreased. After stopping heating, the inner surface temperature decreased much slowly compared with the indoor air temperature, so that the value of inner surface heat flux did not change to negative until the third cycle, indicating that the composite-PCW released heat to indoor air.

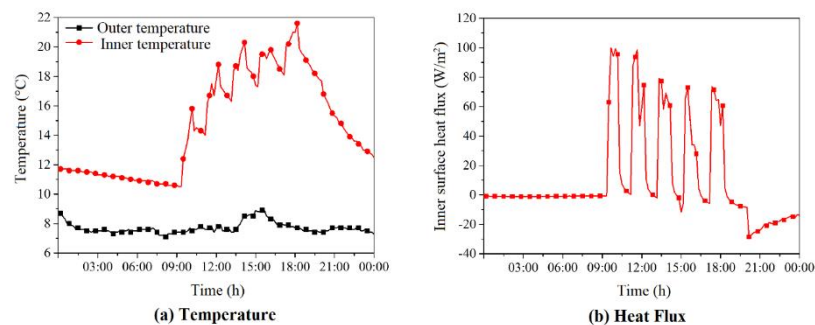


Figure 4. The variations of surface temperatures and inner surface heat flux of the composite-PCW in case 1.

3.2. Case 2: heating 2h + suspension 2h

Figure 5 presents the variations of the indoor and outdoor air temperatures in case 2. The outdoor air temperature was decreasing during the test period. In the three operation cycles, the indoor air temperature changed greatly. It was only around 8°C before the heating process of the first operation cycle, and increased rapidly after heating at 9:00. After 0.5 hours heating, the changing rate became slower, and finally the indoor air temperature rose to 31.46°C in the 2 hours heating process in the first cycle. After stopping heating, the indoor air temperature decreased to 13.52°C. For the three operation cycles, the indoor air temperature could remain above 15°C for more than 1.5h because of the wall heat storage and release. And the indoor air temperature fluctuation was around 18°C.

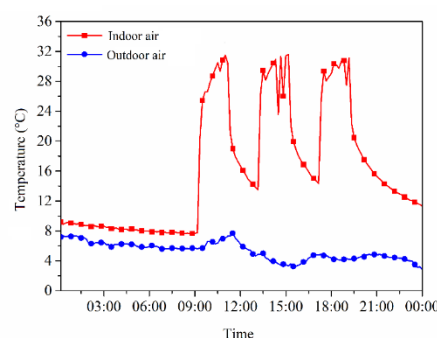


Figure 5. The variations of indoor and outdoor air temperatures in case 2.

The surface temperature variations of the composite-PCW was shown in Figure 6(a). During the test period, the variation of the outer surface temperatures were similar with the outer air temperature variation. The inner surface temperature of the composite-PCW changed greatly with the indoor air temperature variation, and showed a clear warming trend. The wall heat storage during the 2 hours heating process of each cycle maintained the inner surface temperature relatively constant, so that the fluctuation range was only about 6°C. Figure 6(b) shows the inner surface heat flux variation of the composite-PCW. From 0:00-9:00, the inner surface heat flux was maintained at around 0. After heating

at 9:00, the heat was transferred into the wall inner surface, so that the inner surface heat flux rose rapidly. The inner surface heat flux decreased rapidly after stopping heating, and the wall released heat to indoor environment. In the last two operation cycles, the heat transferred into the composite-PCW decreased gradually because of the wall heat storage.

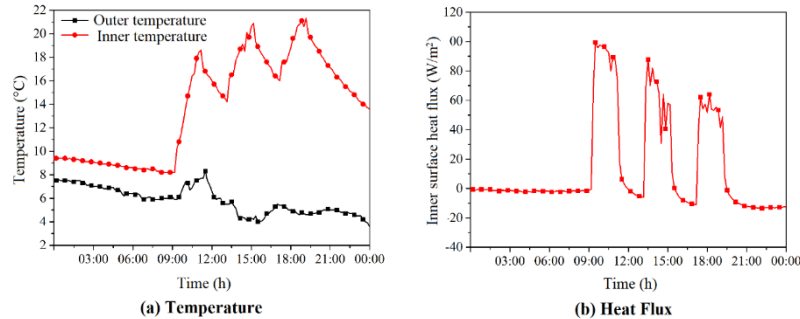


Figure 6. The variations of surface temperatures and inner surface heat flux of the composite-PCW in case 2.

4. The heat storage and release processes

In the whole cycle of intermittent heating (τ_0 - τ_2), the wall begins store heat while the indoor air temperature rises after heating at τ_0 . And the wall releases heat while the indoor air temperature decreases after stopping heating at τ_1 , and the heat release process do not end until the end of the intermittent cycle at τ_2 . The heat storage utilization rate η , the ratio of the effective heat release of the wall in the cooling-down period to the effective heat storage in the heating period, is given in Equation (1).

$$\eta = \frac{\int_{\tau_1}^{\tau_2} h_i (T_i - T_{in}) d\tau}{\int_{\tau_0}^{\tau_1} h_i (T_{in} - T_i) d\tau} \quad (1)$$

Where, h_i is inside convective heat transfer coefficient, W/(m $\cdot$ °C); T_{in} are indoor air temperature, °C; T_i are inner surface temperatures, °C.

Table 2 presents the heat storage utilization of the composite-PCW in the last cycle of the two cases. For case 1, the heat transferred into the wall inner surface was 209.07 kJ/m ^{2} during the heating process. The heat lose to indoor environment was only 10.65 kJ/m ^{2} in the 1 hour cooling-down process, which indicated that there was still a large amount of heat stored in the composite-PCW. The inner surface temperature was higher than 18°C, and the wall had large heat release potential. For case 2, the η in the last operation cycle was 14.86%. The heat release of the composite-PCW in the cooling-down process helped maintain the indoor environment. The heating energy consumption can be reduced by stopping the heating equipment in advance while the indoor thermal comfort is not affected by rationally using the heat storage and release of the composite-PCW.

Table 2. The heat storage utilization of the composite-PCW in the two conditions.

Conditions	Heat storage (kJ/m ^{2})	Heat release (kJ/m ^{2})	η
Case1-cycle 5	209.07	10.65	5.09%
Case2- cycle 3	363.90	54.09	14.86%

5. Conclusion

This paper experimentally studied the dynamic thermal performance of building envelope. The following conclusions have obtained:

1) The indoor air temperature changed greatly during the short intermittent heating conditions. With the intermittent heating operation, the heat storage of the room increased, and the dynamic thermal response of the indoor air accelerated. The indoor air temperature fluctuations were around 14°C and 18°C respectively for case 1 and case 2 when the indoor thermal processes reached relatively stable

2) For case1, the wall thermal process became relatively stable in the last three cycles, and the inner surface temperature of the composite-PCW was always higher than 16°C. For case 2, the wall heat storage in the 2 hours heating remained the inner surface temperature relatively stable. The inner surface temperature fluctuations of composite-PCW were 5°C and 6°C respectively for case 1 and case 2.

3) The heat storage utilization rates were 5.09% and 14.86% for the last cycles of case 1 and case 2 respectively, which indicates that there was a large amount of wall heat storage which can be used to improve the indoor thermal environment. In the short intermittent conditions, the heat transferred into the wall during the heating period was stored inside the wall to improve the indoor thermal environment by maintain the inner surface temperature during the cooling-down period

This work can provide guidance about the practical short intermittent heating. However, the heating thermostat could influence the wall thermal process, which could be addressed in future research.

6. References

- [1] Peeters L, Van der Veken J, Hens H, Helsen L, D'haeseleer W 2008 Control of heating systems in residential buildings: current practice *J. Energy and Buildings* 40 pp 1446-55
- [2] P.T. Tsilingiris 2006 Wall heat loss from intermittently conditioned spaces – the dynamic influence of structural and operational parameters *J. Energy and Buildings* 38 pp 1022-1031
- [3] G.Barrios, G.Huelsz, J.Rojas 2012 Thermal performance of envelope wall/roofs of intermittentair-conditioned rooms *J. Applied Thermal Engineering* 40 pp 1-7
- [4] Dengjia Wang, Yanfeng Liu, Yingying Wang, Jiaping Liu 2014 Numerical and experimental analysis of floor heat storage and release during an intermittent in-slab floor heating process *J. Applied Thermal Engineering* 62 pp 398-406
- [5] Zhe Wang, Borong Lin, Yingxin Zhu 2015 Modeling and measurement study on an intermittent heating system of a residence in Cambridgeshire *J. Building and Environment* 92 pp 380-386
- [6] Ogoli David Mwale 2003 Predicting indoor temperatures in closed buildings with high thermal mass *J. Energy and buildings* 35 pp 851-862
- [7] Cheng V., Ng E., Givoni B 2005 Effect of envelope color and thermal mass on indoor temperatures in hot humid climate *J. Solar Energy* 2005 78 pp 528-534
- [8] Krupa I, Nógellová Z, Špitalský Z, et al. 2014 Phase change materials based on high density polyethylene filled with microencapsulated paraffin wax *J. Energy Convers Manage* 87 pp 400-409
- [9] Y. Dutil, D.R. Rousse, N.B. Salah, et al. 2011 A review on phase-change materials: mathematical modeling and simulations *J. Renewable and Sustainable Energy Reviews* 1 pp 112–130
- [10] A.M. Khudhair, M.M. Farid 2005 A review on energy conservation in building applications with thermal storage by latent heat using phase change materials *J. Energy Conversion and Management* 2(45) pp 263–275
- [11] Yinping Zhang, Kunping Lin, Yi Jiang, Guobing Zhou 2008 Thermal storage and nonlinear heat-transfer characteristics of PCM wallboard *J. Energy and Buildings* 40 pp 1771-1779
- [12] A.Castell, I Martorell, M. Medrano, G. Perez, L.F. Cabeza 2010 Experimental study of using PCM in brick constructive solutions for passive cooling *J. Energy and Buildings* 42 pp 534-540
- [13] Xu Wang, Hang Yu, Lu Li, Mei Zhao 2016 Experimental assessment on the use of phase change materials (PCMs)-bricks in the exterior wall of a full-scale room *J. Energy Conversion and Management* 120 pp 81-89
- [14] Yanru Li, Mengwei Wang, Yin Zhang and Enshen Long 2018 The dynamic thermal process of indoor environment and building envelope during intermittent heating *J. Indoor and built environment*

Acknowledgments

This project is funded by the National Key R&D Program of China (2016YFC0700400), and the National Natural Science Foundation of China (51478280 and 51778382).