Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 158 (2019) 4772–4777

Energy Procedia

www.elsevier.com/locate/procedia

10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China

Experimental investigations for applying PESS to disaster relief PTHs

Caixia Wang[a,b], Shiming Deng[a], Xuefeng Liu[c], Guanyu Fang[a], Wenjing Chen[a], Enshen Long[b,*], Jianlei Niu[a,d,e]

[a] *Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, China*
[b] *Institute for Disaster Management and Reconstruction, Sichuan University, Chengdu, China*
[c] *School of Electric Power, South China University of Technology, Guangzhou. China*
[d] *School of Architecture, Design and Planning, and* [e] *School of Civil Engineering, The University of Sydney, Australia*

Abstract

In disaster relief reconstructions, the severe indoor thermal environment of the prefabricated temporary house (PTH) limits its massive utilization. Here, the application of phase change material energy storage system (PESS) has been proposed in the full-scale experimental PTH. In the experimental investigations, a movable PESS was designed aiming at regulating the indoor environment of the PTH during the daytime in hot summer, by charging the cool energy during the nighttime. The movable PESS revealed positive impacts on the indoor environment regulation in the experimental PTH. In addition, the distance between the PESS and the west wall also had influences on the cool energy discharging of the PESS and the indoor thermal environment of the experimental PTH.

Peer-review under responsibility of the scientific committee of ICAE2018 – The 10th International Conference on Applied Energy.

Keywords: disaster-relief; prefabricated temporary houses; phase change materials; summer; experiments

1. Introduction

Prefabricated temporary houses (PTHs) are massively used in disaster relief reconstructions due to their convenient transport, easy installation and short construction period. In the 2008 Wenchuan earthquake in China, more than 21 million victims were resettled in massive PTHs during post-disaster transitional period, as shown in Fig. 1. Mostly, the rapidly installed PTHs were the un-alternative choice of victims during post-disaster transitional period. In some conditions, the transitional period of victims may last for several months to several years. However, the indoor thermal environment of the PTHs was severe, specifically intolerable in summer [1]. The long-term

1876-6102
Peer-review under responsibility of the scientific committee of ICAE2018 – The 10th International Conference on Applied Energy.
10.1016/j.egypro.2019.01.722

severe indoor thermal environment could result in physical and mental illness of occupants in PTHs [2]. Improving the indoor thermal comfort of PTHs by reasonable methods is in urgent need, extremely in situation of disaster relief reconstructions.

Fig. 1. Prefabricated temporary houses intensively used in disaster relief in the 2008 Wenchuan earthquake in China

In current studies, to reach the target of improving indoor thermal environment, different technologies and insulation materials have been used in conventional buildings, such as aerogel, gas filled panel, closed cell foam, vacuum insulation panel, phase change materials (PCMs) [3]. PCMs have the characteristics of high latent heat and small temperature changes during the phase change process, thus making the PCM application [4-8] possible and extensive in buildings. Cabeza et al. [9] developed a kind of innovative concrete, which enabled the use PCMs as part of building structure, for good structural strength as well as indoor comfort improvement. The study result showed that the buildings using the innovation concrete can provide their occupants with a better indoor thermal environment than those using conventional concrete. Castell et al. [10] experimentally compared the indoor thermal environment in different passive houses in the Mediterranean regions. The comparisons were based on using different bricks, insulation materials and phase change materials. In addition, the actual energy consumption and reduced CO_2 emissions were also studied. Lee et al. experimentally investigated the thermal performance of PCMs incorporated panel [11].

Despite majority of PCM applications in buildings, seldom PCM applied in light-weight prefabricated houses. As the actual use of PTHs may no longer be temporary, it became highly necessary to explore the use of PCMs in PTHs for improving their indoor thermal environment, for the well-beings of disaster victims.

Nomenclature

T_i	The air temperature inside the PTH (^oC)
T_o	The outdoor air temperature (^oC)
D_{pw}	The distance between the PESS and the west wall (mm)

* Corresponding author. Tel.: +86-138-8024-7554.
E-mail address: xxh36335@gmail.com

2. Experimental PTH, PESS and measurements

2.1 Experimental PTH

For experimental study, a prefabricated temporary house (PTH) was set up in Chengdu, China. The PTH was located on flat roof of Sichuan University, as shown in Fig. 2. The full-scale experimental PTH featured conventional prefabricated temporary house in market of China, both in materials and construction dimension. The

PTH consisted of wood and light-weight prefabricated insulation panels. The detailed information of construction materials and their thermal properties are shown in Table 1. Additionally, one T-type thermocouple probe which located in the center of the PTH was used to measure the air temperature inside the PTH (T_i), one thermocouple probe located outside the PTH was used to measure the outdoor air temperature (T_o). Before the measurements, all the T-type thermocouple probes were calibrated in advance, with accuracy of ± 0.5 ºC. All the database of the T-type thermocouple probes were collected by a data logger, with 5 minutes time interval.

Table 1 Properties of used materials in the PTH

Properties	Envelopes	Thickness (mm)	Thermal conductivity (W/ m·K)	Density (kg/m^3)	Specific heat (J/ kg·K)
Steel	Wall and roof	0.5	45.28	8000	460
EPS	Wall and roof	75	0.035	20	1100
Wood	Floor	13	0.15	521	1630

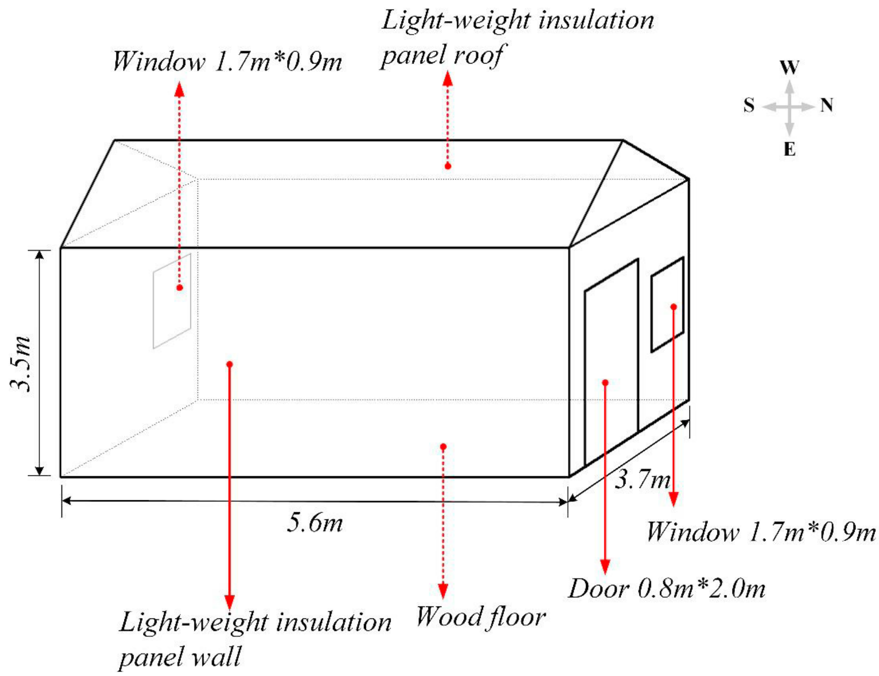

Fig. 2. Illustrations of the experimental PTH

2.2 Experimental PESS

A movable PCM energy storage system (PESS) was specially made to be placed inside the experimental PTH. It consisted of (ⅰ) a supporting steel shelf, (ⅱ) a plastic net-shape container for holding PCM-tubes and (ⅲ) PCMs inside tubes. The physical and thermal properties of PCMs and the details of PESS are given in Table 2 and Table 3, respectively. Totally there were 1240 tubes which were horizontally tiled onto the plastic net-shape container. Inside each tube, 120g PCM was filled. The container was suspended on the steel shelf, with variable distances from the west wall, as shown in Fig. 3. Such a configuration for the PESS would enable the largest possible heat transfer surface area between the PCMs and indoor air. Furthermore, since the solar heat gain by the west wall would be the highest in the afternoon, the PESS was therefore placed close to the west wall, as shown in Fig. 4. In addition, since the PESS was movable, the distance between the PESS and the west wall (D_{pw}) was variable. Therefore, experiments can be carried out with the PESS be placed at different D_{pw} for comparison purposes.

Table 2 Properties of the PCM in PCM energy storage system

Properties	Value
Base material	Inorganic salts
Phase change temperature	18-26 ^{o}C
Latent heat	216kJ/kg
Specific heat capacity	1785J/(kg•K)
Thermal conductivity	0.25-0.5W/(m•K)
Density at (16-28 ^{o}C)	1300kg/m^3
Encapsulation material	Aluminum composite membrane
Flammable	Nonflammable
Toxicity	Non-toxic

Table 3 The detailed configuration of PCM energy storage system

Parameters	Value
Parameters of phase change material tube	
Weight of one PCM tube	120g
Length of one PCM tube	175mm
Width of one PCM tube	35mm
Thickness of PCM tube	15-20mm
Total PCM tubes in PESS	1240
Dimension of PESS	
Length of PESS	5500mm
Height of PESS	3500mm
Thickness of PESS	20mm

Fig. 3. The movable PESS placed inside the PTH

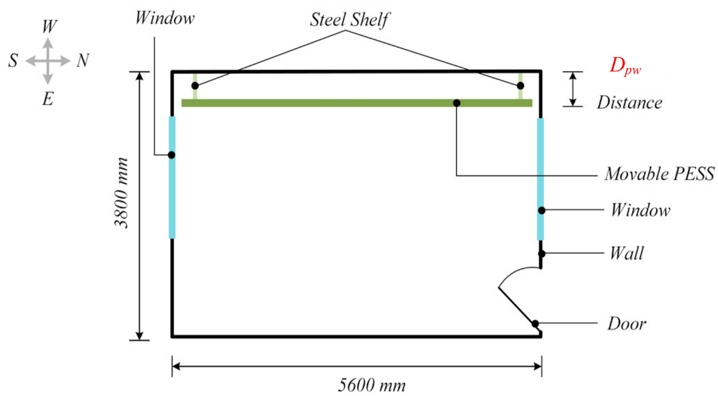

Fig. 4. Top view of the PESS placed inside the PTH

3. Measured results and discussions

The experiments were carried out in the summer of August and September, with two Stages. In Stage 1, the movable PESS was not placed inside the experimental PTH, and in the Stage 2, the movable PESS was placed inside the experimental PTH. During the experiments period, doors and windows were closed and there was no mechanical ventilation provided.

The measured indoor and outdoor air temperatures on the selected 48 hours for Stage 1 are shown in Fig. 5, and those for Stage 2 are in Fig. 6. As seen, although on four different days, the T_o in two Stages had similar hourly variation trends, with the starting and ending temperatures at around 23.5 ºC and 26 ºC, and the lowest and the highest temperatures at around 20 ºC and 32 ºC, respectively. For the four days, the daily average outdoor air temperatures were at around 24.8 ºC. On the other hand, in the Stage 1, the air temperature inside the PTH, T_i, was 20-42 ºC. However, in the Stage 2, the air temperature inside the PTH, T_i, was 20-33.5 ºC. Due to the exist of the PESS, the highest temperature value of T_i was declined from 42 ºC to 33.5 ºC.

Therefore, as seen from Fig. 5 and Fig. 6, the use of the PESS helped lower the air temperatures inside the experimental PTH, thus providing an improved thermal environment inside the experimental PTH in summer.

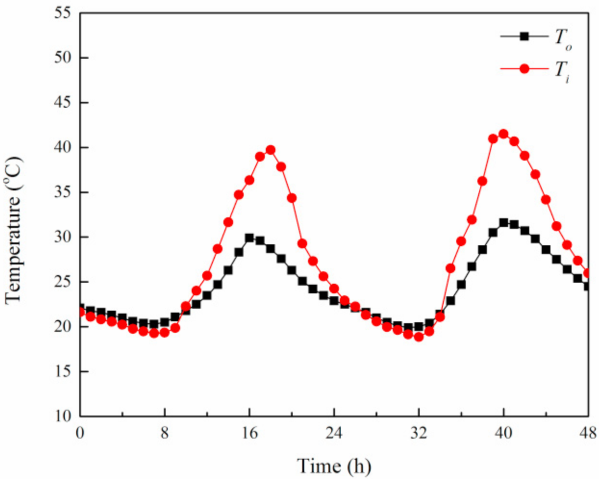

Fig. 5. Comparisons of indoor and outdoor air temperatures in Stage 1

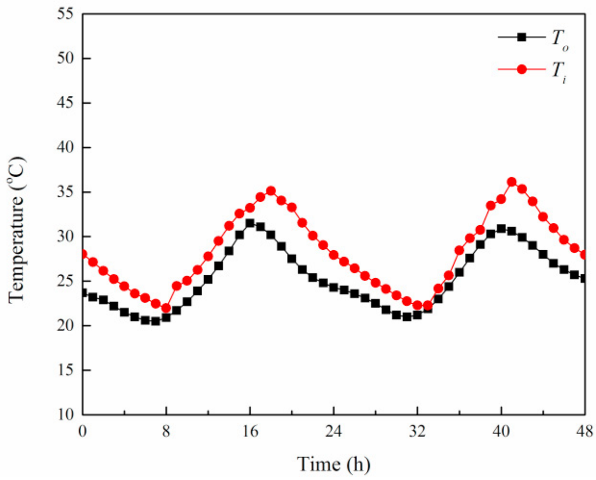

Fig. 6. Comparisons of indoor and outdoor air temperatures in Stage 2

The comparison studies of the PTH with and without the PESS showed that the PESS had significant influences on regulating the indoor air temperature and providing better indoor thermal environment of the PTH. Additionally, the optimisation of the distance between the PESS and the west wall (D_{pw}) was further studied.

Fig.7-9 show the results of cool energy release situations after whole night's cool energy charging of the PESS. In Fig.7, when the D_{pw} was 200mm, the indoor air temperature profile of the PTH had a shape increase at the beginning, and then rose with a slowing down coefficient till the moderate changing. It could be seen that the PESS (D_{pw} = 200mm) maintained the room air temperature between 22-30 ºC for 35 minutes. In Fig.8, when the D_{pw} was 100mm, the indoor air temperature profile of the PTH had a quick increase, and then rose steadily. The PESS (D_{pw} = 100mm) maintained the maintain the room air temperature between 22-30 ºC for 70 minutes, 35 minutes longer than the time duration when D_{pw} was 200mm. In Fig.9, when the D_{pw} was 0mm, the indoor air temperature profile of the PTH rose almost in a same stable rate. The PESS (D_{pw} = 0mm) maintained the maintain the room air temperature between 22-30 ºC for 100 minutes, 65 minutes longer than the time duration when D_{pw} was 200mm.

It could figure out that, after a whole night's cool energy charging of the PESS, the comfort temperature (22-30 ºC) time duration of the PTH varied when the D_{pw} of the PESS was different. The comfort temperature time duration of the PTH was 100 minutes when the D_{pw} was 0mm, was 70 minutes when the D_{pw} was 100mm, was 35 minutes when the D_{pw} was 200mm. In other words, the PTH provided longer comfort indoor thermal environment when D_{pw} was 0mm.

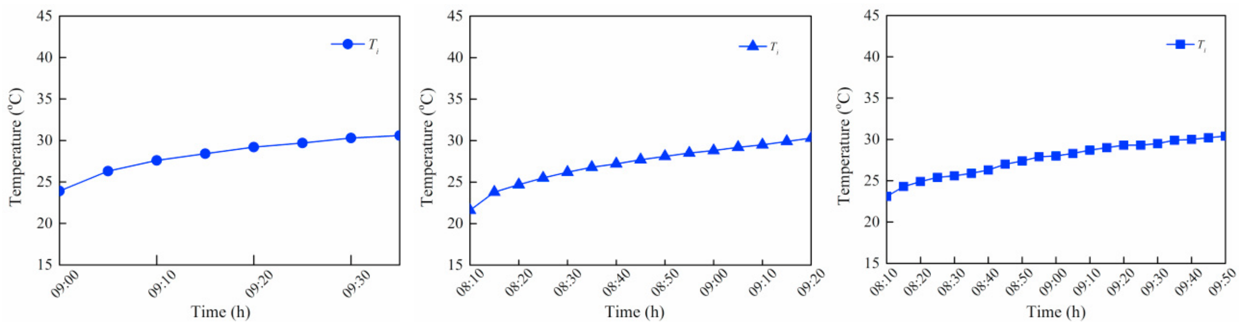

Fig. 7. Temperature profiles of indoor air temperatures (D_{pw}=200mm), Fig. 8. (D_{pw}=100mm) and Fig. 9. (D_{pw}=0mm)

4. Conclusions

In this study, a full-scale TPH with PESS was designed and experimentally investigated. With applying the PESS to the PTH, effective indoor thermal regulation became feasible, the average indoor air temperature of the PTH with PESS was lower than it of the PTH without PESS. Due to the exist of the PESS, the highest temperature value of T_i was declined from 42 ºC to 33.5 ºC. Additionally, after a whole night's cool energy charging of the PESS, the comfort temperature (22-30 ºC) time duration in the daytime of the PTH varied with the different D_{pw} of the PESS. The comfort temperature time duration of the PTH was 100 minutes when the D_{pw} was 0mm, was 70 minutes when the D_{pw} was 100mm, was 35 minutes when the D_{pw} was 200mm. The PTH provided 65min longer comfort indoor thermal environment with the D_{pw}=0mm when compared with the D_{pw}=200mm. Therefore, the D_{pw}=0mm was preferred when selecting the distance between the PESS and the west wall. The distance between the PESS and the west wall had influences on the cool energy discharging of the PESS and the indoor thermal environment of the PTH.

Acknowledgements

The authors gratefully acknowledge the financial supports from the Hong Kong Polytechnic University, Hong Kong Jockey Club, and Sichuan University. In addition, the support by the National Natural Science Foundation of China (No. 51478280) is acknowledged.

References

[1] L.H. Huang, E.S. Long, J.L. Ouyang, Measurement of the Thermal Environment in Temporary Settlements with High Building Density after 2008 Wenchuan Earthquake in China, 9th International Symposium on Heating, Ventilation and Air Conditioning (Ishvac) Joint with the 3rd International Conference on Building Energy and Environment (Cobee), 121 (2015) 95-100.
[2] F. Ascione, N. Bianco, R.F. De Masi, F. de' Rossi, G.P. Vanoli, Energy refurbishment of existing buildings through the use of phase change materials: Energy savings and indoor comfort in the cooling season, Appl Energ, 113 (2014) 990-1007.
[3] S.Y. Yu, X.D. Wang, D.Z. Wu, Microencapsulation of n-octadecane phase change material with calcium carbonate shell for enhancement of thermal conductivity and serving durability: Synthesis, microstructure, and performance evaluation, Appl Energ, 114 (2014) 632-643.
[4] M. Kenisarin, K. Mahkamov, Passive thermal control in residential buildings using phase change materials, Renewable and Sustainable Energy Reviews, 55 (2016) 371-398.
[5] PCMs for Residential Building Applications: A Short Review Focused on Disadvantages and Proposals for Future Development, Buildings, 7 (3) (2017) 78.
[6] T. Silva, R. Vicente, F. Rodrigues, Literature review on the use of phase change materials in glazing and shading solutions, Renew Sust Energ Rev, 53 (2016) 515-535.
[7] A. Figueiredo, R. Vicente, J. Lapa, C. Cardoso, F. Rodrigues, J. Kampf, Indoor thermal comfort assessment using different constructive solutions incorporating PCM, Appl Energ, 208 (2017) 1208-1221.
[8] V.V. Tyagi, A.K. Pandey, D. Buddhi, S.K. Tyagi, Exergy and energy analyses of two different types of PCM based thermal management systems for space air conditioning applications, Energ Convers Manage, 69 (2013) 1-8.
[9] L.F. Cabeza, C. Castellón, M. Nogués, M. Medrano, R. Leppers, O. Zubillaga, Use of microencapsulated PCM in concrete walls for energy savings, Energ Buildings, 39 (2) (2007) 113-119.
[10] A. Castell, I. Martorell, M. Medrano, G. Pérez, L.F. Cabeza, Experimental study of using PCM in brick constructive solutions for passive cooling, Energ Buildings, 42 (4) (2010) 534-540.
[11] K.O. Lee, M.A. Medina, E. Raith, X. Sun, Assessing the integration of a thin phase change material (PCM) layer in a residential building wall for heat transfer reduction and management, Appl Energ, 137 (2015) 699-706.