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ARTICLE

A Study for the Influence of the Location of PCMs Assembly System on Improving Thermal Environment inside Disaster-Relief Temporary Houses

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ABSTRACT

Currently, people pay more and more attention to the transitional resettlement of victims after various natural disasters. There is an urgent need for a large number of temporary houses to resettle the victims after natural disasters. Disaster-relief temporary houses (DTHs) played an important role in the post-disaster resettlement in the past, which can not only be produced on a large scale, but also can be quickly and conveniently erected, which were the main means to solve the problem of transitional resettlement. However, due to their temporary nature, there was no extra energy consuming system installed in the DTHs generally. Hence the indoor thermal environment inside the DTHs was severe in summer. In this study, combined with the field experimental tests of the DTHs in Wenchuan Earthquake and Lushan Earthquake and the experimental study of the full-size DTH, it found that the thermal environment inside the DTH was intolerably high in summer. It had negative impact on victims. In order to improve the thermal environment inside DTHs during post-disaster period which lacked of extra energy resources, this study used the method of combining phase change materials (PCMs) with walls of the DTH to explore its feasibility and effectiveness. The results showed that PCMs could effectively improve the thermal environment inside the DTH in summer. Furthermore, the difference of the composite positions between PCMs and the wall affected the improvement effect. The energy release rate of the PCMs assembly system (PAS) varied according to the positions of the PCMs.

KEYWORDS

Disaster-relief temporary houses (DTHs); phase change materials (PCMs); indoor thermal environment

Nomenclature

Tia:	The air temperature inside the DTH, °C
Toa:	The outdoor air temperature, °C
Tei:	The internal surface temperature of the east wall for the DTH, °C
Twi:	The internal surface temperature of the west wall for the DTH, °C
Tsi:	The internal surface temperature of the south wall for the DTH, °C
Tni:	The internal surface temperature of the north wall for the DTH, °C
Teo:	The external surface temperature of the east wall for the DTH, °C
Two:	The external surface temperature of the west wall for the DTH, °C

Tso:	The external surface temperature of the south wall for the DTH, °C
Tno:	The external surface temperature of the north wall for the DTH, °C
Tw_p:	The temperature thermocouple for the surface a. of PAS, °C
Te_p:	The temperature thermocouple for the surface b. of PAS, °C

Abbreviations

DTHs:	Disaster-relief temporary houses
PCMs:	Phase change materials
PAS:	PCMs assembly system
PVT:	Photovoltaic thermal

1 Introduction

Energy is the basis of the survival and development of human [1,2]. The energy issue has become a worldwide problem—the dilemma situation [3] between the upsurge of energy demand and the shortage of non-renewable energy resources supply [4]. When it comes to social energy consumption, what should be pointed out is that the building energy consumption accounts for a large proportion of total social energy consumption. At present, building energy consumption accounts to approximately 30% of the total energy consumption of the whole society in China [5−7]. This proportion (30%) is foreseen to be increased continuously from the experience of developed countries, which is the result of large-scale population urbanization and high-speed economic development of China [8,9].

With continuously increasing of building energy consumption, building energy-saving has become a significant issue of the whole construction industry. Certain new technologies, methods and materials have been used in order to reduce energy consumption in the construction industry, such as phase change materials (PCMs), gas filled panel, vacuum insulation panel, aerogel and vacuum insulation panel. Among them, PCMs have been paid attention due to their high latent heat, convenient installation and energy storage characteristic [10−14]. Main methods to incorporate PCMs with buildings include independent PCMs energy storage system, incorporate PCMs with buildings' envelopes and direct modification of building materials with PCMs. Cabeza et al. [15] developed an innovation concrete, the innovation concrete gave an opportunity of PCM in structural use, it obtained good structural stress together with thermal comfort improvement properties. As their investigation showed, the innovation concrete building provided more comfortable indoor thermal environment compared with conventional concrete buildings. Lee et al. [16] reported an experimental study about the incorporation of PCMs with panels. Castell et al. [17] studied passive houses' environment in Mediterranean district by experimental comparisons. These comparisons made up of the using of PCMs, perforated bricks and common bricks and insulation materials. Besides, the executive energy consumption and CO_2 emissions were studied under the circumstances of the existing of cooling load.

Current PCM applications in buildings mainly include energy efficiency improving of buildings and building energy consumption reducing. In buildings, the applications of PCM are mainly through the following ways: Storage the solar energy with PCM energy storage system, and use the storage energy in cold winter to reduce the building energy consumption, or storage the cool energy through the cool outdoor air and release the storage energy to reduce the room air temperature in summer; appropriate use of PCM can reduce indoor air temperature fluctuation, improving the indoor environment comfort level; weaken or postpone the energy consumption peak value. Lin et al. [18] provided solutions of thermal performance improvement by composite the residential building with PCMs and solar photovoltaic thermal (PVT) collectors. They did series on-site tests considering the arrangement of different PCM, selection of insulation materials, optimization of incorporation forms. With the database from the experiments, they calibrated and optimized the model of the whole test system. Lee et al. [19] completed researches about mitigating the energy demand in California under coastal and transitional climates, the thermal performance of the phase change frame wall had been tested.

There are majority of studies about the application of PCMs in permanent buildings, however, studies on PCMs in light-weight temporary houses are rare. Wang et al. [20] made a series of study of thermal performance of passive prefabricated house, but did not take the PCM incorporation method during the optimization period. Lv et al. [21] investigated the thermal performance of light-weight building composited with PCM, however, the application scope of this study is limited. In this study, the PCM have been composited in prefabricated house, and the application scope have been expanded.

In western China, for instance Xinjiang, Tibet, Qinghai, the temperature difference between day and night can reach up to 30°C at most, 12°C generally in summer period. During summer period of Kashi and Yinchuan, 87% of the days have large temperature difference between day and night (daytime peak temperature is no less than 28°C and nighttime bottom temperature no higher than 16°C). Consequently, it is a praiseworthy work to storage the cool energy in nighttime and release the energy in hot daytime. Hence in this study, the cool energy is prepared to store in PCMs aiming to regulate the indoor thermal environment of DTHs in summer period. In this paper, firstly, the field experimental tests for DTHs are presented. This is followed by reporting the full-scale experimental DTH and the experimental PCMs assembly system. Thirdly, results of field experimental tests and experimental study are presented. Finally, a conclusion is given.

2 Field Experimental Tests of Thermal Environment inside Disaster-Relief Houses in Wenchuan Earthquake and Lushan Earthquake

After Wenchuan Earthquake and Lushan Earthquake, in order to comprehensively and systematically evaluate the thermal environment inside DTHs in summer, the research team went deep into the post-disaster settlement sites at the first time and carried out a large number of field experimental tests. The effects on victims' physiology and psychology from the thermal environment inside DTHs in summer were analyzed.

2.1 DTHs in Wenchuan Earthquake

The field experimental tests of DTHs in Wenchuan Earthquake included on-the-spot monitoring and questionnaire survey on the thermal environment inside DTHs in summer, from July to August. The sites of field experimental tests included Beichuan Qiang Autonomous County, Mianzhu City, Mianyang City, Jiangyou City, Dujiangyan City and so on.

Equipment for monitoring the thermal environment inside DTHs in summer included portable infrared temperature monitor, dry bulb thermometer, SW300 thermal comfort instrument and so on. And the test period was 11:00–18:00 (avoid sleep period, as far as possible to reduce interference to the daily life of victims).

In order to better analyze the subjective thermal feeling, psychological state and common diseases of victims in DTHs, methods of questionnaire and on-the-spot monitoring were used at the same time. Taking into account the acceptance of victims, the questions set in the questionnaire were easy to understand, with the number of surveys distributed at each settlement ranging from 50 to 100. At the same time, in the process of issuing the questionnaire, the researchers observed and recorded the physical and mental state of victims by chatting, so as to further understand the physical and mental state of victims.

2.2 DTHs in Lushan Earthquake

The field experimental tests of DTHs in Lushan Earthquake included on-the-spot monitoring and questionnaire survey on the thermal environment inside DTHs in summer, from July to September.

The equipment for monitoring the indoor thermal environment of disaster-relief buildings in summer included Detu temperature recorder and humidity recorder 175H1, and the test period was 9:00–19:00 (avoiding the sleep period, reducing the interference to the daily life of the victims).

Similar to the questionnaire survey after Wenchuan Earthquake (by understanding the victims' subjective feelings about the living environment, including physiological, psychological and health changes before and after the earthquake, to help understand the living environment of disaster-relief buildings), this survey adhered to the main ideas of the Wenchuan post-disaster survey. Also, the field investigations used the questionnaire survey method, and focused on understanding the problems of the living environment in the hot summer weather. In order to reflect the characteristics of temporary accommodation for disaster-relief, the questionnaire was illustrated in details, so that victims could understand and answer it easily.

3 The experimental DTH, PAS and Measurements

On the basis of the field experimental tests of DTHs, a universally representative experimental DTHs has been set up.

3.1 The Experimental DTH

The experimental DTH was located on flat roof of a four-story building of Sichuan University in Chengdu, China, and the orientation of the building was 45 degrees north-east. In construction dimension and materials, the experimental DTH was a representative of the DTH in market. Main structural materials of the experimental DTH are light-weight fabricated insulation panel l-EPS, light-weight fabricated insulation panel II, reinforced concrete and wood. The details about the structural materials and their thermal properties are shown in my previously study [22] and briefly introduced here in Tab. 1 and Tab. 2, respectively.

Table 1: Materials of building envelope in DTH. Adapted with permission from [22]. Copyright © 2018, Elsevier

Building envelope	Material
Roof	Light-weight fabricated insulation panel l-EPS
External wall	Light-weight fabricated insulation panel II-Rock wool
Floor	Wood
Foundation	Reinforced concrete

Table 2: Properties of the used materials in DTH. Adapted with permission from [22]. Copyright © 2018, Elsevier

Properties of the materials	Thickness (mm)	Thermal conductivity (W/m·K)	Density (kg/m^3)	Specific heat (J/kg·K)
Steel sheet	0.5	45.28	8000	460
Insulation material l-EPS	75	0.035	20	1100
Insulation material II-Rock wool	50	0.041	71	1100
Wood	13	0.15	521	1630

The experimental DTH was a full-scale test room, the dimension of the test room was 3.8 m × 5.6 m × 2.7 m with two 1.7 m × 0.9 m windows, one 2.0 m × 0.8 m door, the detailed illustration is as shown in Fig. 1.

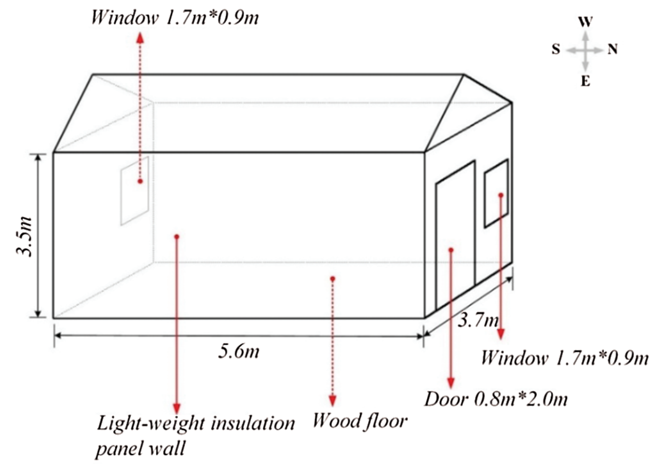

Figure 1: Illustration of experimental DTH. Adapted with permission from [22]. Copyright © 2018, Elsevier

3.2 Experimental PAS

The experimental PCMs assembly system (PAS) was installed in the DTH, the PAS consisted of sodium sulfate phase change material, PCM tubes shaped "curtain" pattern energy storage container and a removable steel shelter whose distance between building wall was flexible, as the illustration in Fig. 2. The PAS was used as retrofit system.

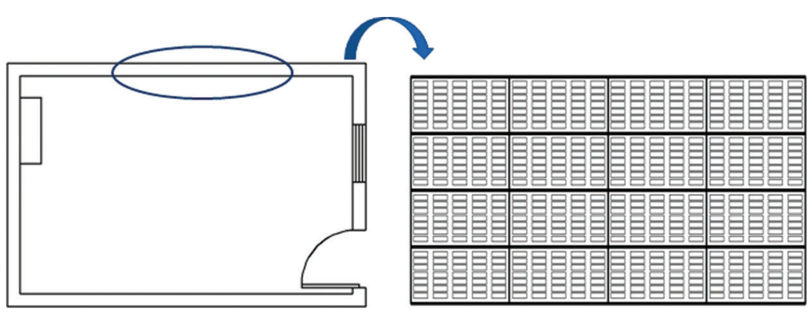

Figure 2: Illustration of PCMs assembly system in DTH

In detail, the "curtain" pattern PCMs assembly system was filled with PCM tube, and the properties of the sodium sulfate phase change material are as shown in Tab. 3. The configuration of PAS is given in Tab. 4.

3.3 Measurement Details

In the experiments, aim at testing the thermal performance of DTH and PAS, several calibrated T-type thermocouple probes (accuracy: ± 0.5°C) were used. And a data logger JTDL-80 (interval time: 5 min) was used to collect data.

For the test in DTH, eight thermocouple probes were used to test the indoor air temperature, *Tia*, two thermocouple probes were used to test the outdoor environment temperature, *Toa*, four thermocouple probes for the internal surface temperature of wall (*Tei, Twi, Tsi, Tni*), four thermocouple probes for the external surface temperature of wall (*Teo, Two, Tso, Tno*), as shown in Fig. 3.

Table 3: Properties of the PCM in PCMs assembly system. Adapted with permission from [22]. Copyright © 2018, Elsevier

Properties	Value
Base material	Inorganic salts
Phase change temperature	18–26°C
Operating temperature	0–60°C
Latent heat	216 kJ/kg
Specific heat capacity	1785 J/(kg • K)
Thermal conductivity (solid or liquid)	0.5 W/(m • K)
Thermal conductivity (phase change)	0.25 W/(m • K)
Density at (16–28°C)	1300 kg/m³
Total enthalpy at 16–28°C (heating)	50 kWh/m³
Total enthalpy at 16–28°C (cooling)	58 kWh/m³
Averaged specific heat capacity (heating)	4.17 kWh/(m³•K)
Averaged specific heat capacity (cooling)	4.83 kWh/(m³•K)
Encapsulation material	Aluminum composite membrane
Flammable	Nonflammable
Toxicity	Non-toxic

Table 4: The detailed configuration of PCMs assembly system. Adapted with permission from [22]. Copyright © 2018, Elsevier

Parameters	Value
Parameters of phase change material tube	
Weight of one PCM tube	100–120 g
Length of one PCM tube	175 mm
Width of one PCM tube	35 mm
Thickness of one PCM tube	15–20 mm
Total PCM tubes in PAS	1024
Dimension of PCMs assembly system	
Length of PAS	5500 mm
Height of PAS	3500 mm
Thickness of PAS	20 mm

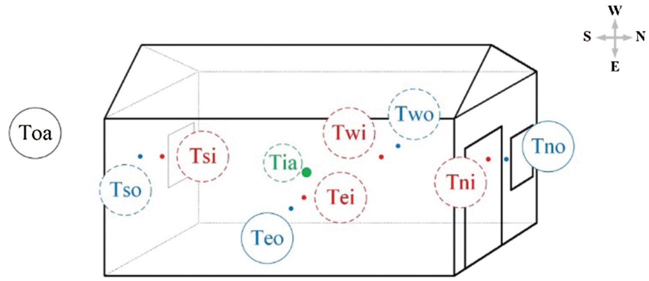

Figure 3: Distribution of T-type thermocouple probes in DTH

Secondly, in order to study the thermal performance of "sheet" pattern energy storage container-PAS, more T-type thermocouple probes had been pasted on the PAS, including 6 thermocouple for the surface a. of PAS Tw_p, and 6 for the surface b. of PAS Te_p, which were evenly distributed on the surface of PCM. The detailed distribution of T-type thermocouple probes of PAS is shown in Fig. 4.

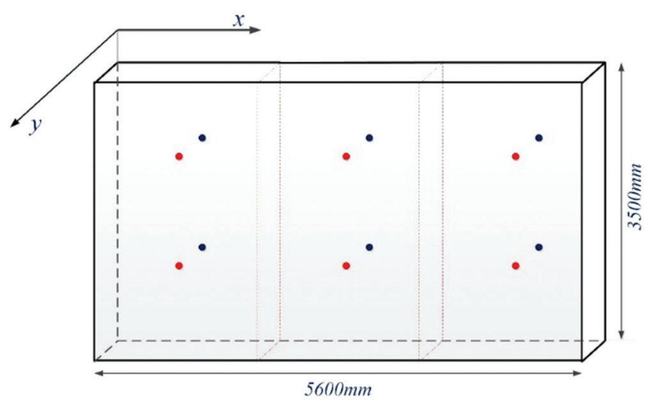

Figure 4: Distribution of T-type thermocouple probes in PAS

4 Results

Based on the field experimental tests of disaster-relief houses in Wenchuan Earthquake and Lushan Earthquake and experimental study of full-scale DTH in Sichuan University, results of thermal environment inside DTHs are described in details below. The results included two parts, the first part was the field experimental test results, and the second part was the experimental test results. Additionally, there were no extra electric appliances and no meals were cooked in the DTHs. The obtained results were typical for the observations. The DTHs in the field experimental tests and the experimental study represented those typical conventional DTHs in the current Chinese market, in terms of both dimensions and envelope materials.

4.1 Results of field experimental tests

Through the filed measurements and investigations of the indoor thermal environment of relief-houses after Wenchuan Earthquake and Lushan Earthquake in summer, large quantities of field monitoring and questionnaire survey data was obtained. The summary and analysis of the field monitoring and questionnaire survey data of disaster-relief houses in Wenchuan Earthquake and Lushan Earthquake are shown in followings.

Fig. 5 shows the comparison between the outdoor ambient temperature and the indoor temperature of DTHs. During the period from 12:00 to 15:00, the change of outdoor air temperature was basically the same as that of indoor air temperature in DTHs. The peak value of outdoor air temperature reached its peak at about 13:50. The peak indoor air temperature of No. 1 and No. 4 DTH was arrived about 13:40, at around 35.8°C. And the highest difference between indoor and outdoor air temperature was 5°C. Even though the indoor air temperatures of different DTH were different, compared with the outdoor air temperature, the excess range was about 5°C. It could be predicted that, in the weather with more intense solar radiation, the difference between indoor and outdoor air temperature of DTHs would continue to increase.

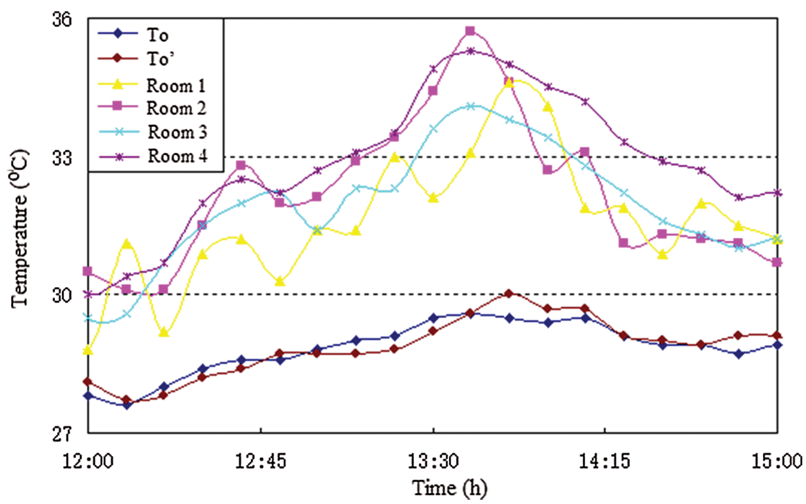

Figure 5: The difference between outdoor air temperature and air temperature inside DTHs

Fig. 6 shows the comparison between outdoor air temperature and the inner surface temperature of the DTH. It showed that the inner surface temperature of the envelope was in the following order: The inner surface of the roof, the inner surface of the west wall, the inner surface of the north wall and the inner surface of the south wall. The temperature of the inner surfaces of the wall was different. The higher temperature on the inner surface of the west wall was due to the fact that the west wall had been exposed to solar radiation for a longer time and there was no sunshade, while the inner surface of the south wall was less exposed to the sun because it was blocked by DTH's eaves and the opposite building. Specifically, the inner surface temperature of roof was rather high. When outdoor ambient temperature peaked at 29°C, the inner surface temperature of roof already exceeded 55°C.

From Figs. 5 and 6, it could be seen that air temperature inside the DTH greatly exceeded the outdoor air temperature, and exceeded the comfortable temperature range of human body, causing a strong sense of discomfort to victims. Coupled with the fact that the inner surface temperature of DTH's envelope was higher than indoor air temperature, the long-wave radiation from the envelope structure continued to warm the indoor air and brought an extremely uncomfortable sense to the human body.

On the other hand, 510 collected questionnaires from Wenchuan Earthquake and Lushan Earthquake were carefully summarized and analyzed, and would be described in details as followings. The result shows the distribution of the stay time of victims in DTHs on sunny and cloudy days. In sunny days, 56.1% of the people stayed in DTHs for 0–4 h. In sharp contrast, in cloudy days, more than 73.2% of the people stayed in DTHs for more than 4 h, it showed that indoor thermal environment inside the DTH was an important factor affecting the activities of victims. Additionally, the most intolerable factors in DTHs were verified from the questionnaire survey. The most unbearable factors for victims in DTHs included stifling heat, humidity, mosquitoes, lack of ventilation, and so on. 88.66% of victims thought that stifling heat in DTHs was the most serious problem, which further confirmed that improving the thermal environment inside DTHs was a serious problem that should be solved. From the statistics of mental state changes of victims in DTHs, we can see that more than 35% of victims had negative changes in their mental state, and 34.21% of them had become extremely serious. Combined with the above challenges to the human endurance of the harsh indoor thermal environment of the building, the life of victims in DTHs had brought severe negative effects on their physical and psychological health.

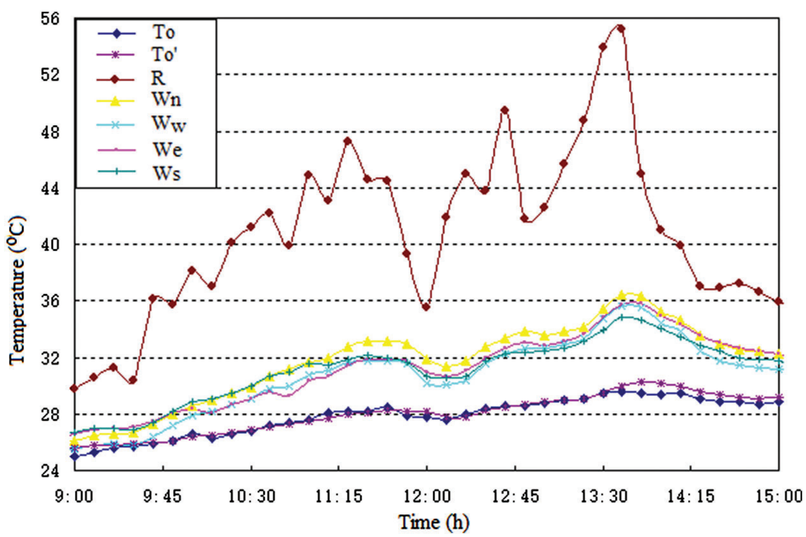

Figure 6: The difference between outdoor air temperature and inner surface temperatures of DTHs

As thermal environment inside DTHs was severe in summer, victims took various feasible means try to alleviate the suffered discomfort. The main measures taken included turning on the electric fan, increasing sunshade, increasing ventilation, sprinkling water and so on. In order to cope with the hot and muggy indoor conditions of DTHs in summer, 49% of victims chose to turn on electric fans to cool down, which was limited by the condition of the post-disaster transition phase. In addition, the behavior of improving the indoor thermal environment of DTHs by increasing sunshade and ventilation accounted for 25%. The increase of sunshade reduced the heat, and increased ventilation accelerated the heat dissipation of DTHs. Additionally, reseachers had adopted other measures such as sprinkling water to cool down. However, these simple methods of shading or ventilation had little effect on improving thermal environment inside DTHs, further measures need to be taken to effectively improve thermal environment inside DTHs.

4.2 Results of Experimental Study

In summer period, the temperature data of different thermocouple probes as mentioned in 3.3 was collected. The experimental process was divided into three parts. Firstly, the thermal performance of the DTH without PAS was studied. Secondly, with an air conditioner of 1.5 TR, the cool energy has been stored into the PAS, and the indoor air temperature was maintained between 22 and 25°C. Thirdly, based on the distance flexible PAS, three different distances between PCM and the west wall (200 mm, 100 mm, 5 mm) was selected, purposing on further study of the PAS.

The comparison of outdoor air temperature and indoor air temperature without PAS is shown in Fig. 7. Fig. 7 showed that outdoor air temperature varied from 24°C to 37°C. Indoor air temperature range was from 25°C to 43°C in the selected 5 days in summer. It should be pointed out that outdoor air temperature was the average value of T27 and T28, and indoor air temperature was the average value of T33-T40 (located at different height in test room). In addition, outdoor environment was severe (up to 37°C), and indoor air temperature was much higher than outdoor air temperature (up to 43°C), the difference between indoor and outdoor air temperature was up to 6°C. From the comparison, it was clear that the DTH can magnify the heating reflection in summer period, the indoor air temperature of DTH was above the thermal comfort temperature ranges all day, thus the regulation of room air temperature of DTH was required which was consistent with the previous field experimental tests results.

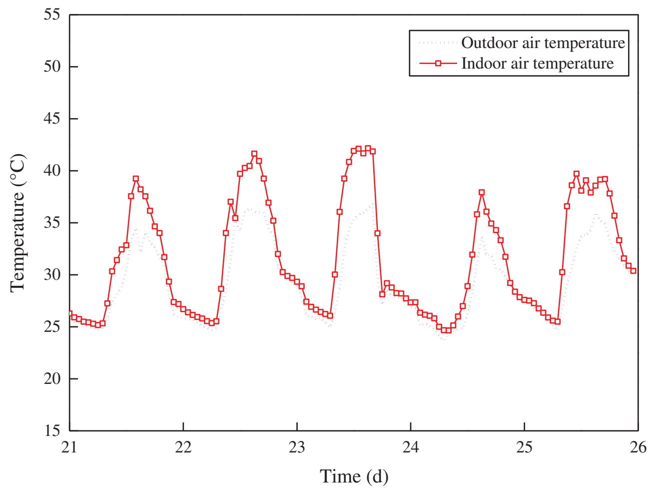

Figure 7: Comparison of outdoor air temperature and air temperature inside DTH in summer

In order to regulate the room air temperature of DTH, the PCMs assembly system was designed and tested in the DTH. The comparison of indoor air temperature with and without PAS and outdoor air temperature is shown in Fig. 8. Fig. 8 shows that the indoor air temperature with PAS was lower than the indoor air temperature without PAS (up to 7°C) in transition season. It proved that the PCMs assembly system had obvious effect on regulating the indoor air temperature of DTH. Furthermore, the PAS could delay the peak temperature and release the temperature fluctuation during the daytime.

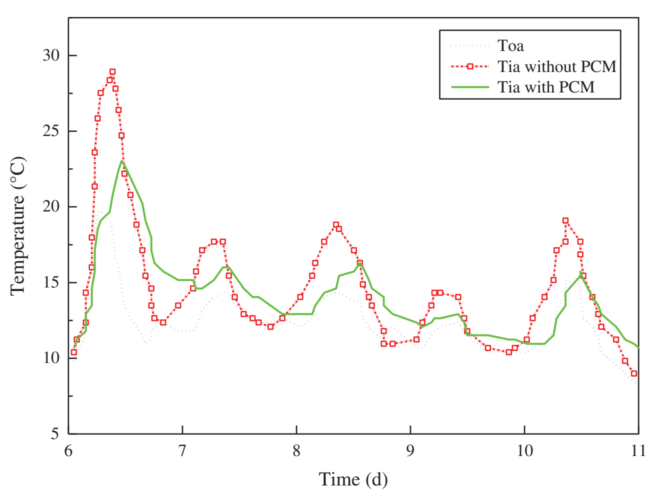

Figure 8: Temperature profiles of DTH with and without PAS in transition season

As shown in the comparisons of DTH indoor thermal performance with and without, the PAS could improve the thermal comfort level inside the experimental DTH. In addition, the searching of thermal reaction of PAS and the inter-reaction between PAS and DTH caused more attention of study. In addition, the method of time interval comparison under certain temperature range was adopted to analyze the thermal reaction of PAS and inter-reaction between PAS and DTH. In the research, an air conditioner was used in the test room, the core value of the air conditioner in the research was accelerating the cool energy storage process, and maintaining the initial thermal situations of PAS and DTH were the same. The PAS has been set in different positions (Position 1, Position 2, Position 3) in the DTH.

In Figs. 9−11, PCMs stored the cool energy from air conditioner during the nighttime and released the cool energy at daytime. As shown in Fig. 9, temperature profiles of T19 and T30 had shape increases from 9:00~9:30 and increased steadily from 9:30~14:30. With the distance of PAS and the west wall of 200 mm, the experimental DTH can maintain indoor air temperature at 22°C~30°C for 35 min. It also could be seen that the temperature of PAS surface a. and PAS surface b. had the common fluctuation with the temperature rise of indoor air, the obvious inflection points revealed when the room air temperature exceeded the phase change upper limit temperature of PCMs.

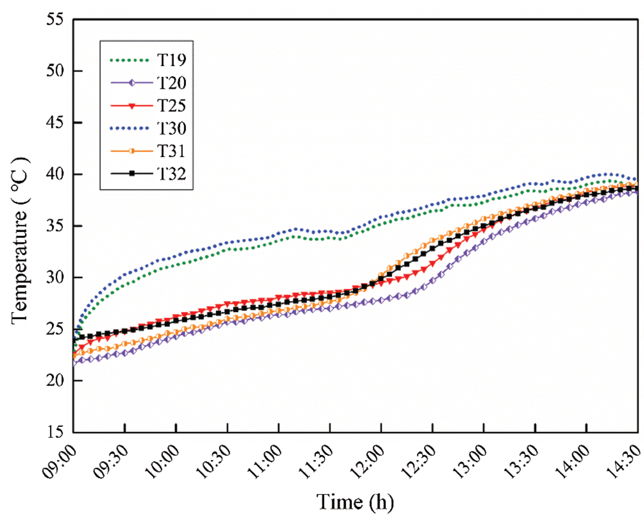

Figure 9: Temperature profiles of PCMs and indoor air (Position 1: With distance of 200 mm)

Fig. 10 shows the temperature profiles of T19 and T30 had a quick increase after switching off air conditioner, and then slowing down the step of temperature rise. With the distance of PAS and the west wall of 100 mm, the experimental DTH can maintain indoor air temperature at 22°C~30°C for 70 min (35 min longer than the time of distance of 200 mm).

Fig. 11 reveals the temperature changing of T19 and T30 were almost in a same rate after switching off air conditioner. With the distance of PAS and the west wall of 5 mm, the experimental DTH can maintain indoor air temperature at 22°C~30°C for 100 min (65 min longer than the time of distance of 200 mm).

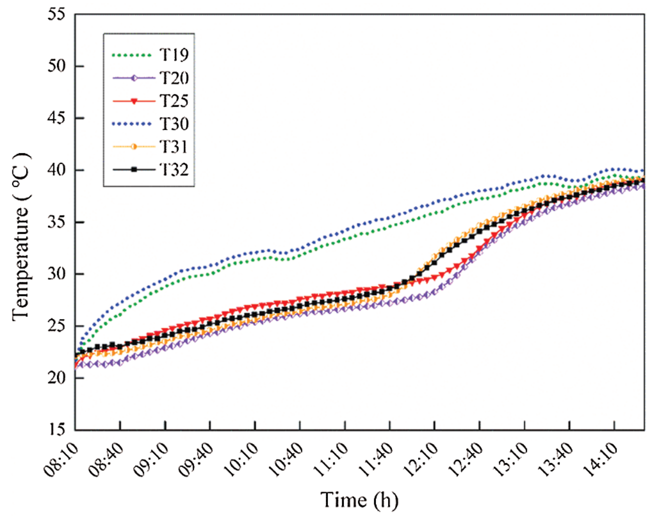

Figure 10: Temperature profiles of PCMs and indoor air (Position 2: With distance of 100 mm)

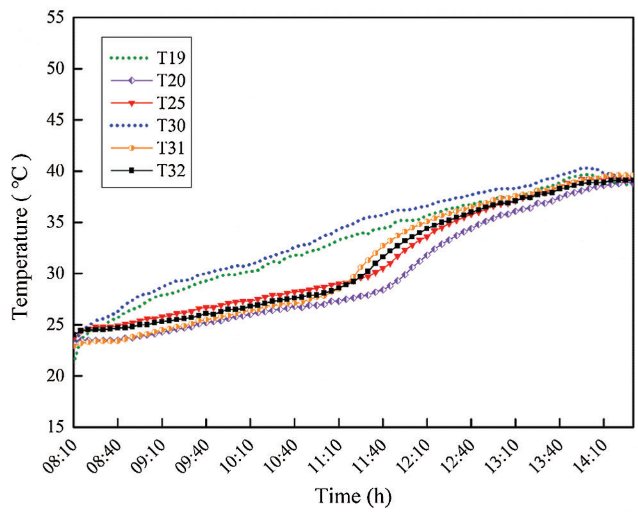

Figure 11: Temperature profiles of PCMs and indoor air (Position 3: With distance of 5 mm)

5 Conclusion

This paper reports an study on field experimental tests on DTHs and applying PCM to DTHs for improving their internal thermal environment inside in summer. Field experimental tests for DTHs and experimental PCMs assembly system in full-scale experimental DTH are presented. From results and analysis of field experimental tests and experimental study, the DTH revealed severe thermal conditions in summer period, the intolerable rate of occupants in the prefabricated house could reach up to 37%. With the application of PCM in the DTH, effective indoor thermal regulation became feasible. With the different positons of PAS in the DTH, the energy release rate of the PAS varied. With the distance of PAS and the west wall of 5 mm, the experimental DTH can maintain indoor air temperature at 22°C~30°C for 100 min (65 min longer than the time of distance of 200 mm, 30 min longer than the time of distance of 100 mm).

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. Wei, W. J., Samuelsson, P. B., Tilliander, A., Gyllenram, R., Jonsson, P. G. (2020). Energy consumption and greenhouse gas emissions during ferromolybdenum production. *Journal of Sustainable Metallurgy, 6(1),* 103–112. DOI 10.1007/s40831-019-00260-8.
2. Topcu, E., Altinoz, B., Aslan, A. (2020). Global evidence from the link between economic growth, natural resources, energy consumption, and gross capital formation. *Resources Policy, 66(2),* 101622. DOI 10.1016/j.resourpol.2020.101622.
3. Aditya, L., Mahlia, T. M. I., Rismanchi, B., Ng, H. M., Hasan, M. H. et al. (2017). A review on insulation materials for energy conservation in buildings. *Renewable and Sustainable Energy Reviews, 73,* 1352–1365. DOI 10.1016/j.rser.2017.02.034.
4. de Wilde, P. (2014). The gap between predicted and measured energy performance of buildings: A framework for investigation. *Automation in Construction, 41(2),* 40–49. DOI 10.1016/j.autcon.2014.02.009.
5. Li, B. Z., Yao, R. M. (2009). Urbanisation and its impact on building energy consumption and efficiency in China. *Renewable Energy, 34(9),* 1994–1998. DOI 10.1016/j.renene.2009.02.015.
6. Zhao, H. X., Magoules, F. (2012). A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews, 16(6),* 3586–3592. DOI 10.1016/j.rser.2012.02.049.
7. Yao, R. M., Li, B. H., Steemers, K. (2005). Energy policy and standard for built environment in China. *Renewable Energy, 30(13),* 1973–1988. DOI 10.1016/j.renene.2005.01.013.
8. Chen, H. Y., Jia, B. S., Lau, S. S. Y. (2008). Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy. *Habitat International, 32(1),* 28–40. DOI 10.1016/j.habitatint.2007.06.005.
9. Chen, M. X., Zhang, H., Liu, W. D., Zhang, W. Z. (2014). The global pattern of urbanization and economic growth: Evidence from the last three decades. *PLoS One, 9(8),* e103799. DOI 10.1371/journal.pone.0103799.
10. Sadineni, S. B., Madala, S., Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews, 15(8),* 3617–3631. DOI 10.1016/j.rser.2011.07.014.
11. Santamouris, M., Synnefa, A., Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy, 85(12),* 3085–3102. DOI 10.1016/j.solener.2010.12.023.
12. Mosaffa, A. H., Ferreira, C. A. I., Talati, F., Rosen, M. A. (2013). Thermal performance of a multiple PCM thermal storage unit for free cooling. *Energy Conversion and Management, 67,* 1–7. DOI 10.1016/j.enconman.2012.10.018.
13. Ascione, F., Bianco, N., De Masi, R. F., de' Rossi, F., Vanoli, G. P. (2014). Energy refurbishment of existing buildings through the use of phase change materials: Energy savings and indoor comfort in the cooling season. *Applied Energy, 113(2),* 990–1007. DOI 10.1016/j.apenergy.2013.08.045.
14. Yu, S. Y., Wang, X. D., Wu, D. Z. (2014). Microencapsulation of n-octadecane phase change material with calcium carbonate shell for enhancement of thermal conductivity and serving durability: Synthesis, microstructure, and performance evaluation. *Applied Energy, 114,* 632–643. DOI 10.1016/j.apenergy.2013.10.029.
15. Cabeza, L. F., Castellón, C., Nogués, M., Medrano, M., Leppers, R. et al. (2007). Use of microencapsulated PCM in concrete walls for energy savings. *Energy and Buildings, 39(2),* 113–119. DOI 10.1016/j.enbuild.2006.03.030.
16. Lee, K. O., Medina, M. A., Raith, E., Sun, X. (2015). Assessing the integration of a thin phase change material (PCM) layer in a residential building wall for heat transfer reduction and management. *Applied Energy, 137(7),* 699–706. DOI 10.1016/j.apenergy.2014.09.003.

17. Castell, A., Martorell, I., Medrano, M., Pérez, G., Cabeza, L. F. (2010). Experimental study of using PCM in brick constructive solutions for passive cooling. *Energy and Buildings, 42(4),* 534–540. DOI 10.1016/j.enbuild.2009.10.022.
18. Lin, W., Ma, Z., Cooper, P., Sohel, M. I., Yang, L. (2016). Thermal performance investigation and optimization of buildings with integrated phase change materials and solar photovoltaic thermal collectors. *Energy and Buildings, 116,* 562–573. DOI 10.1016/j.enbuild.2016.01.041.
19. Lee, K. O., Medina, M. A. (2016). Using phase change materials for residential air conditioning peak demand reduction and energy conservation in coastal and transitional climates in the State of California. *Energy and Buildings, 116(6),* 69–77. DOI 10.1016/j.enbuild.2015.12.012.
20. Wang, Y., Wang, L., Long, E., Deng, S. (2016). An experimental study on the indoor thermal environment in prefabricated houses in the subtropics. *Energy and Buildings, 127(1),* 529–539. DOI 10.1016/j.enbuild.2016.05.061.
21. Gao, H., Lv, Y. J., Liu, G., Chen, T. (2012). Study on relation between layout of building and wind speed ratio based on numerical simulation. *2012 World Automation Congress,* Puerto Vallarta, Mexico.
22. Wang, C. X., Huang, X., Deng, S. M., Long, E. S., Niu, J. L. (2018). An experimental study on applying PCMs to disaster-relief prefabricated temporary houses for improving internal thermal environment in summer. *Energy and Buildings, 179(4),* 301–310. DOI 10.1016/j.enbuild.2018.09.028.