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Parametric study of the impact of incorporated PCM inside a lightweight wall on indoor temperature fluctuations

R.M. Saleh[1] , M.A. Said [1,2], W.G. Alshaer [1] and S.A. Nada[1,2]
[1]Mechanical Engineering Department, Benha Faculty of Engineering, Benha University, Benha, Egypt.
[2]Egypt-Japan University of Science and Technology, Alexandria, Egypt.
E-mail: rami.saleh@bhit.bu.edu.eg

Abstract

Background: The utilization of phase change materials (PCM) in the building structure for thermal regulation has attracted considerable interest from researchers. The PCM can be integrated at various locations inside the building's outside walls, resulting in a unique thermal behavior of the structure. Nevertheless, the prevailing research predominantly The focus of this study is on an experimental test rig in a certain climate, and phase change materials (PCM) are not effective enough at controlling temperature in lightweight structures in those conditions. Consequently, two experimental test rigs (one with PCM and one without) of identical dimensions were constructed and analyzed in this study to examine the variations in interior temperature across different ambient conditions without mechanical systems. The findings reveal a significant seasonal influence of phase change materials (PCMs) on the thermal efficiency of lightweight structures, with varying contributions across different ambient temperatures. and the rate of internal surface temperature attenuation in the summer season can be diminished by 7 % compared to the reference wall. In addition to PCMs, they can effectively mitigate indoor temperature fluctuations, reducing the maximum indoor temperature. The research findings can offer a theoretical foundation and empirical evidence for the effective utilization of PCMs in lightweight structures.

Keywords: Lightweight walls; Extruded polystyrene XPS; Indoor temperature fluctuations

1. Introduction

In the last few years, lightweight structures have been significantly developed owing to their ease of construction and sustainability. Nonetheless, while lightweight structures exhibit superior thermal insulation, their thermal mass, or thermal energy storage capacity, is inferior, resulting in inadequate temperature fluctuation suppression compared to conventional buildings (1). The delay and reduction of the solar heat on the outer wall during summer are minimal, leading to elevated internal temperatures. The internal temperature of prefabricated walls can surpass the external conditions by 10 C. Significant changes in interior temperature substantially reduce thermal levels as well markedly elevate air-conditioning energy usage as shown by Wang et al. (2). Phase change materials (PCMs) have attracted considerable interest from architects and mechanical engineers for their potential application in free cooling (3, 4, 5, 6) and building construction as innovative solutions regarding this matter. PCMs have the ability to absorb a lot of heat within a compact volume at a high temperature and then release it when the temperature is reduced, thus mitigating internal temperature variations (7, 8). Numerous research has proven the capability of PCM that will enhance thermal efficiency of prefabricated structures. Soares et al. (9) assess the energy usage percentage through various temperature areas in Europe when integrated PCM in prefabricated steel constructions, utilizing Energy Plus models with a reduction of 10 to 60%. Lei et al. (10) investigated incorporating phase change materials (PCMs) in prefabricated steel in Singapore and found an annual reduction in energy by 21% to 32%. Furthermore, Long et al. (11) determined through numerical simulation indicating the annual energy usage of lightweight structures incorporating PCM might be lowered by 23.85% in humid subtropical environments. Research conducted by Gao (12) and Jia(13) et al. has illustrated incorporating PCMs from type paraffin 25 inside building components. by utilizing computational fluid dynamics,such as thermal insulation materials (TIM) and hollow bricks significantly enhances thermal performance, decreasing the radiation rate from 13.07% to between 0.92% and 1.93%, while extending the delay duration from 3.83 hours to between 8.83 and 9.83 hours. Li et al. (14) concluded that incorporating PCM inside foamed concrete by utilizing the Energy Plus model analysis might decrease annual heating energy usage approximately 4.74%.Furthermore, Mukram et al. (15) examined the optimum placement and thermal behavior of PCM from type (ME29P) on brick walls via a mathematical model, demonstrating a significant improvement in heat transfer through the wall, with peak heat gain being decreased by 32% and the indoor temperature lowered 1.2°C when the PCM is positioned distally from the source of heat. Three test walls constructed from bricks using distinct air cavity geometries (square, polygonal, and circular) via CFD and incorporated various types of phase change materials (RT-42, capric acid, RT-24, and n-eicosane) to assess their impact on the thermal efficiency on the test room. It was discovered that when the PCMs occupy the square voids of bricks, the indoor heat transfer and energy usage diminish by as much as 67.84% and 61.8%, respectively, as investigated by Allam et al. (16). The improvement of thermal behavior in buildings utilizing phase change materials (PCMs) is primarily contingent upon the materials ability to store and release heat, influenced by the relation among the wall layer and outside temperature (17, 18). Consequently, multiple research was conducted on the effects of PCM on structures subjected to diverse heat environments. from these individuals, Sarri et al. (19) established through CFD analysis that shading devices incorporated with PCM under ambient conditions markedly enhanced the thermal comfort of inside hours across the majority of Algerian climate zones owing to the phase shifting of PCMs, that capable of releasing and absorbing substantial energy as latent heat, with potential energy investments ranging from 44.13% to 59.11%. Sun et al. (20) illustrated an impact of paraffin-based (PCMs) incorporated into lightweight structures in humid climates on energy consumption via Energy Plus. The findings indicated the overall energy-saving rate decreased from 1.64% to 1.32% in contrast to an increase in humidity levels from 40% to 90%. The appropriate selection and thermal performance of PCMs depend on climatic conditions and solar radiation, as shown by Fateh and Zwanzig(21, 22). My conclusion is that PCMs are capable of increasing thermal efficiency in buildings; nevertheless, their efficacy is affected by both the design of the building and external thermal conditions. Although the aforementioned studies yield numerous significant conclusions, the majority concentrate on numerical simulations under specified climate circumstances, leaving its efficacy in real-world contexts unexamined. Accordingly, Kumar et al. (23) illustrated an experiment incorporating shape-stabilized PCM inside gypsum board through varying PCM and graphene weight percentages for four days. The results showed that installing on the southern wall and roof would delay the peak temperature by 3-3.5 hours. Additionally, Rathore et al. (24) conducted another experiment over three successive days wherein they incorporated phase change material (OM-35) alongside insulation (polyurethane foam, TIM) within hollow bricks for assessing overall thermal efficiency. Testing revealed the largest reduction of interior temperature reached 11.2%, and the shifting time was around 2 to 2.5 h. These results indicated that EECB is improving interior temperature significantly. Conversely, Patel et al. (25) investigated an experiment to determine the best configuration for three constructions (polyurethane foam, air cavities, and PCMs from type OM-35) incorporated inside concrete blocks. The results indicated that the best configuration was constructed from outside to inside OM-35, OM-35,air,TIM. These configurations can reduce the highest temperature and mean thermal intensity by 12.5°C and 13.4°C, respectively. Nevertheless, researchers noticed which findings had been restricted during the duration of summer months in hot conditions. This evidence proves that the outside environment plays a vital role in the performance of PCM. The results indicate that the majority of contemporary research emphasizes short-term tests and mathematical models, revealing significant deficiencies in the experimental examination of lightweight structures incorporating phase change materials (PCMs) under prolonged natural conditions. Simultaneously, several experimental research studies (26, 27, 28, 29) have predominantly concentrated on the composite. The increase of PCM (salt-hydrate, paraffin-wax, silica matrix incorporating paraffin ,ME29P, etc.) performance with materials like bricks, concrete, and clay walls has been explored, although there is a paucity of experimental investigations on PCM in prefabricated wall structures (TIM-based). Moreover, distinct meteorological conditions constrain the conclusions derived from several investigations across different regions. Ultimately, in light of the divergence between numerical modeling (theoretical attributes) and the actual conditions (intricate attributes), research grounded in empirical measurements is increasingly essential. Consequently, to address these problems, R.M.saleh et al (30) investigated experimental supported with machine learn to the performance of PCM integrated in lightweight wall.the results show that the configuration (2) is best configuration to minimize indoor temperature fluctuations This paper built two identical test rigs, one with (PCM) and another one without them. The purpose was to test the thermal performance, specifically the temperature and comfort of the inside of light-weight buildings that are made with PCM, in a variety of climates without using any machines. This study closes the research gap between simulation studies, which mostly focus on specific climates, and real-world applications by using data from tests that were done in real environments. The research results provide important data and useful information for the use, development, and improvement of PCMs in lightweight structures.

2. Experimental setup and Measurement Parameters

The experimental setup consists of two test rig one with PCM cavities and another one without PCM cavities as a references wall to compare with PCM with cavity.in figure 1 show wall (1) with PCM cavity and reference wall. Each test wall has dimensions 0.5 x0.5 m and thickness 0.087m and consist of three layer cement board, XPS and cement board. Extruded polystyrene 7.5 cm and cement board 0.06 cm for external and internal board. in wall (1) have four cavities filled with PCM. Each cavity has dimensions 0.4 m x 0.075. each test walls are fixed on the exposed cement board heater plate to simulate ambient temperatures .this two heater connected to variable transformer to regulate ambient temperature. The PCM cavities contain RT 24 type phase change materials. The PCM located Infront of room. The thermophysical characteristics of RT 24 was listed in table 1.and the cement board have density of 1400 kg /m^3 ,thermal conductivity is 0.35(W/m.̊c) and specific heat 1400 (j/kg.̊c).in addition to, the extruded polystyrene have thermal conductivity is 0.03 (W/m.̊c) and specific heat 1450 (j/kg.̊c). Temperature sensors are positioned at several locations to monitor temperatures. Thermocouples of type T are employed to measure wall and phase change material temperatures during the discharge process. 24 thermocouples were arranged in two test rigs divided into eight thermocouples to measure temperatures through the reference wall and sixteen thermocouples on wall (1). Four thermocouples were placed in the top and bottom of the cement board from both sides and another four thermocouples in front of the room from both sides for reference wall and wall (1), respectively. Another eight thermocouples were distributed, two for each cavity in wall (1). All data were collected by a data acquisition system and recorded as transient readings on a laptop. The tests and procedures were conducted under varying environments in accordance with the subsequent experimental protocol:

- In discharge protocol, External wall surface temperature 35,40,45°C daytime.

- In charging protocol, external wall surface temperature 18-20°C nighttime.

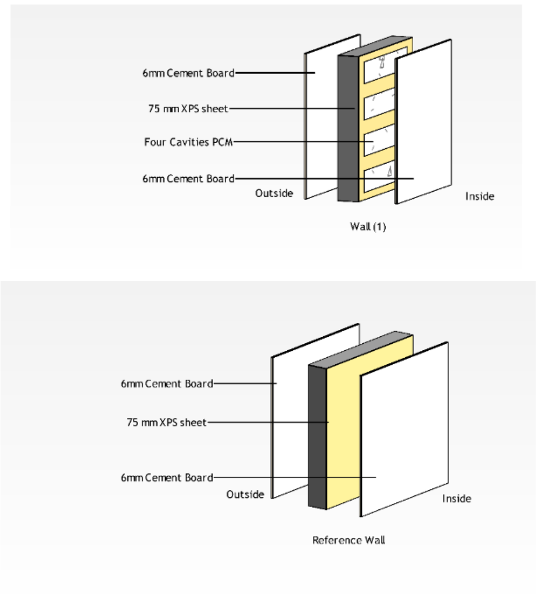

Fig. 1 A schematic diagram of Test walls.

3. Results and Discussion

3.1 Indoor Temperature analysis

Figure 2 illustrates a comparison of wall (1) and the reference wall regarding indoor temperature at an ambient temperature of 45°C. The results indicate that when the ambient temperature exceeds 35 °C, the indoor temperature increases quickly in correlation with the ambient temperature, attributed to the minimal heat storage and low thermal inertia of the reference wall. In comparison, wall (1) integrated with PCM is more effective in reducing heat transfer into the room when temperatures rise because it can store a lot of heat, hence diminishing heat and slowing down temperature escalation. The indoor temperature of wall (1) can be decreased by 1.5°C relative to the reference wall at an ambient temperature of 45°C. This mitigates fluctuations in indoor temperature during periods of peak ambient temperature while also enhancing the thermal performance of lightweight structures, hence improving indoor thermal comfort levels

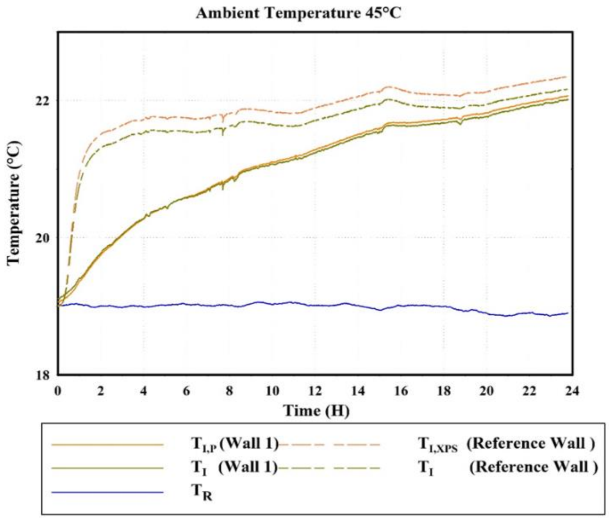

Fig.2 Comparison between Wall (1) and Reference Wall at ambient temperature 45°C.

4. Conclusions

Two test walls are established to study the thermal behaviour of PCM in lightweight building. One with PCM cavities and another one as a reference wall. The following conclusions are derived.

- The utilization of PCM near to inside room reducing indoor temperature by 1.5°C when compared to the reference wall.at ambient temperature 45°C.
- When outdoor temperature increases the indoor temperature will increase rapidly.
- the position of PCM near to inside this show better in winter season.
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Table 1. Thermo-Physical characteristics of RT 24 (Data Sheet)

Physical characteristics	Value
The melting range	21-25 °C
The Congealing range	25-21 °C
Latent heat (±7.5%)	160 kJ/kg
Specific heat capacity	2 kJ/kg.K
Combination of sensible and latent heat (in 15-30 °C range)	42 Wh/kg
Density of solid (at 15 °C)	0.88 kg/l
Density of liquid (at 35 °C)	0.77 kg/l
Volume expansion	12.5 %
Thermal conductivity	0.2 W/m.K
Maximum operation temperature	55 °C

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