Experimental Investigation of Phase Change Material as an Insulator in Hollow Brick Wall

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Abstract. In this paper, an experimental study has been conducted for using a PCM as a thermal insulation material in a south wall of a room. Two identical cubic rooms were fabricated from sandwich panels except for the south wall (test wall) was built as an Iraqi domestic wall. South wall orientation was chosen as the test wall due to the significant amount of solar radiation falling on it so that the study compared two test walls, a wall without PCM or not treated wall (NTW) and a wall embedded with PCM or treated wall (TW). The results show that using PCM in TW will increase the time lag by 1 hour and decrease the inner surface wall and room temperature by about 2.7 °C compared with NTW.

Keywords. Phase change material (PCM), Insulation, Time lag.

1. Introduction

Iraqi climate nature can be classified into two essential seasons, long and hot dry summer and cold-short winter. The variation of daily range temperature is limited and leads to heat assemblage in building walls' components. Therefore, the energy consumption demand will be increasing rapidly, especially in the hot regions due to the utilization of cooling systems. In Iraq, the building sectors consumed about 38% of the total energy produced. In 2025, it is expected that more than six million building units will be built, leading to an increase in energy demand. The integration of phase change materials in building walls is an effective method to enhance walls' thermal performance due to their thermal properties. In addition to its low thermal conductivity, PCM can absorb a large amount of heat during the charging period and release that heat during the discharging process, reducing the cooling load and shifting the peak load to another time. In this paper, we will study experimentally the integration of Paraffin wax with melting point 40℃ into capsules and put it in the hollow brick cavities to enhance thermal insulation in a local construction in Diwaniya city in Iraq. Many experimental and numerical studies about PCM use as an insulation material in building walls are conducted. In this field, a researcher conducted an experimental and numerical study using the FORTRAN language to investigate Gypsum board impregnated with PCM to form a layer adjacent to the wall's exterior side. He found a reduction in the peak room temperature by 4℃ during day time. Also, the reduction in the heating load at night [1]. Other researchers studied experimentally two test rooms, one without PCM and another provided with a horizontal cylinder containing PCM embedded in the wall. It was found that the average reduction of wall heat flux was 15% when 10% PCM concentration was used and 9% when 20% PCM used, while the average space cooling reduced by 8.6% when 10% PCM
used and 10.8% when 20% PCM used [2]. Another researcher presented a numerical study using the FORTRAN language to investigate PCM filled the hollow cylinder of hollow bricks. He found that the reduction in heat gain increase with the increase of PCM amount, and the best location of the PCM cylinder is in the centerline of the brick [3]. Thus, other researchers studied experimentally and numerically using the FORTRAN language a PCM layer incorporated into a wall. They show that a 5 mm of PCM double the available stored energy, which corresponds to an equivalent concrete layer of about 8 mm [2]. Castell et al. [3] made an outdoor experimental test of several cubicles provided constructed from conventional and alveolar brick containing PCM and provided with heat pumps for cooling. They found that the reduction in the inner wall surface's peak temperature by 1°C smooth the daily fluctuation of temperature and reduced 15% in the electrical power, leading to a reduction in the CO₂ emission about 1–1.5 kg/year/m².

Some researchers have also conducted an indoor experimental test of a dynamic simulator room provided with a PCM layer integrated into the walls at different locations. They found that the PCM layer's optimum location is close to the interior side, where the reduction of heat flux and time lag was 41% and 2 hours, respectively [4]. Guarino [5] conducted an experimental and numerical study using EnergyPlus software to investigate a PCM layer adjacent to the interior side of the hot wall placed in a climatic chamber. It was found a reduction of about 20% of energy consumption. Hasan et al. [6] studied experimentally three insulated chambers, one without PCM and two rooms with PCM (one provided with PCM layer close to the interior surface and the other PCM layer close to the exterior surface). They concluded that the PCM layer adjacent to the indoor show the best performance with a reduction in the inside wall temperature, heat gain, and time lag were 8.5%, 2.6 hours, and 44%, respectively. In the same field, other authors were conducted a numerical study using FORTRAN language, a thin layer of PCM integrated at different locations into the walls. The optimal location of the PCM layer that gives a higher thermal performance was found close to the wall's internal surface [7]. Besides, a researcher has also conducted a numerical study using the FORTRAN language to investigate a PCM integrated into a hollow brick. The thermal behavior of temperature inside the brick due to type, quantity, location, and the melting point of PCM inside the brick was studied [8]. Thus, Kumar [9] presented an experimental and numerical study using DesignBuilder software to investigate a PCM integrated into a hollow brick. It was found that the maximum reductions of room temperatures were 6°C and 2°C for January and July, respectively. This work investigates the effect of integrating the PCM in a small sealed tube inserted in the cavities of hollow bricks to enhance the thermal insulation of the conventional Iraqi wall.

2. Problem description

First of all, the model was designed by Solidworks software, as shown in Figure (1) and Figure (2), and then fabricated, as shown in Figure (3). The model of examining the PCM effect consists of two identical cubical rooms with a control chamber in between. The first room is standard, and the second room is a test room (PCM room), while the control chamber contains the measurements record equipment like the computer with other data loggers. Both the test room and standard room contained an ice container as a cooling system, as shown in Figure (1), Figure (2), and Figure (3). The rooms are fabricated from different layers of sandwich panels “rigid polyisocyanurate foam core with an external and internal sheet made of steel with 5 cm thickness for one layer” with thermal conductivity of (0.034–0.038 W m⁻¹ K⁻¹) [10] except the south wall (test wall) made from Iraqi domestic wall (with and without PCM). The foam is used to fill all the model cavities to terminate the ventilation from or to the rooms. The two rooms are identical and with inner dimensions (0.45 m×0.45m×0.45m) for each one, the west and east walls with a thickness of (0.1 m) while the roof with a thickness of (0.15 m) and the ground thickness is (0.2 m). The floor of rooms raised by (0.2 m) height by using Thurmastone brick from the ground to minimize the ground's heat conduction to the rooms' inner space.
2.1. Cooling system
The test rooms contain two identical ice containers fixed at the center of each room's ground as shown in Figure (1) and Figure (2), each container insulated from all sides except the top and contain 9.35 kg of ice. The ice plays a vital role in reducing the rooms' temperature through natural convection to prevent global warming and keep the room temperature profile at the acceptable comfort range.
2.2. Standard room
It is a room set up for comparison to test the south wall. The south wall in this room is an Iraqi domestic wall without PCM (NTW) consist of a (1 cm) of mortar layer with thermal conductivity (1.16 W m$^{-1}$ K$^{-1}$) [11-13] and a hollow bricklayer with a thickness of (10.2 cm) with thermal conductivity (0.812 W m$^{-1}$ K$^{-1}$) [13] followed by (1 cm) of mortar layer. The hollow bricks' cavities are filled with mortar, as shown in Figure (4) and Figure (5).

![Image](standard_room.png)

Figure 4. Standard room.

![Image](schematic_standard_room.png)

Figure 5. Schematic of the standard room.

2.3. PCM Encapsulation
The PCM was encapsulated into identical sealed small tubes (29 mm diameter × 70 mm height × 0.4 mm thickness) dimensions for each one, as shown in Figure (6). The capsules are made from aluminum with thermal conductivity (221 W m$^{-1}$ K$^{-1}$) [12]. The amount of PCM inside one capsule is (35 grams) occupied about (95%) of the total volume of the capsule, while the total weight of the capsule is (55 grams). Sixty capsules are fabricated; all capsules are identical and inserted into the cavities of the inner rows of hollow bricks close to the interior side of the test wall (PCM wall). All the
capsules were tested for over (90) to ensure no leakage of PCM from capsules. The properties of PCM are shown in Table (1) [14].

![Figure 6. PCM capsule.](image)

Table 1. Thermo-physical properties of paraffin wax-based on PCM, [14].

| Property                                      | Values          |
|-----------------------------------------------|-----------------|
| Melting temperature range                     | 38-43 °C        |
| Congealing temperature range                  | 43-37 °C        |
| Heat storage capacity                         | 174 kJ/kg       |
| Specific heats in both solid and liquid states| 2 kJ.kg⁻¹. k⁻¹  |
| Density in solid state                        | 880 kg/m³       |
| Density in liquid state                       | 760 kg/m³       |
| Volume expansion (solid/liquid phase change)  | 16%             |
| Thermal conductivity in both solid and liquid state | 0.2 Wm⁻¹. K⁻¹ |

2.4. Test room
The test room is shown in Figure (7) and Figure (8). This room is identical to the standard room, except the south wall treated with PCM (TW), where the PCM capsules inserted in the inner rows of hollow bricks close to the interior side of the wall instead of mortar that is used in the NTW in the standard room.

![Figure 7. Test room.](image)
2.5. Measurement instruments

2.5.1. Temperature data logger. Data acquisition from Applent company named AT4208 Multi-channel temperature meter with 8 sectors connected to K type thermocouple probes. The thermocouples were calibrated with maximum errors (±0.2°C) and then used to measure the temperature. The data logger was connected to a computer using special software to record the temperature every 15 minutes for 24 hours of the day. The sensors were fixed at the same location in the two standard and PCM walls and the rooms and then used to read the temperature of the south wall outer surface and inner surface in addition to the PCM and rooms temperature for both standard and test rooms.

2.5.2. Weather station. The weather station consists basically of three sensors, as shown in Figure (9). The first sensor is a 108-probe used to measure the air temperature. The second sensor is the three-cup NRG40 anemometers developed by the NRG system to measure the wind speed. The last sensor is the CS300 pyranometer provided by Campbell Scientific, which is used to measure the total solar radiation.
2.5.3. Pyranometer. The solar intensity on the south wall was measured using a small pyranometer model TES-1333/1333R calibrated with an accuracy of ±5%.

3. Experimental procedure

3.1. Design of the model
The model was designed by Solidworks software, as shown in Figure (1) and Figure (2), and then fabricated, as shown in Figure (3).

3.2. Set-up the measurement tools
The weather station is established close to the model while the temperature sensors are fixed in the same location at both the standard room, as shown in Figure (5), and the test room, as shown in Figure (8), to measure the temperature every 15 minutes. The weather station sensors and temperature sensors are connected to data loggers connected to a computer placed in the control room to record the data.

3.3. Calibration of the model
Before the PCM test, the two identical rooms were tested using two identical Iraqi conventional walls with the same design as the south walls. The temperature of the outer and inner surfaces beside the air temperature in both rooms was recorded. The results were found to be the same, so that any change in any test after using PCM capsules will be due to the PCM effect.

3.4. Test procedure
According to the temperature diagram, Figure (10), the hottest period in Iraq lies between July and August, so that this test was done on the 17 of August to test the PCM performance in the highest weather temperature period. In this study, an outdoor test was made for two rooms with and without PCM for 24 hours in the Diwaniya city in Iraq. The test included recording the temperatures, wind speed, and solar radiation.

4. Results and discussion
Figure (10) demonstrates the ambient temperature variations in Diwaniya city in 2019. These values are predicted by Meteonorm software; the figure shows that the peak temperature period between week 24 and week 35 of the year, where this period is the hottest in Iraq. Figure (11) shows the solar radiation on both the horizontal surface (roof) and south wall during the test day (17 August). The maximum radiation on the roof (horizontal surface) was (884.5 w/m2) at midday, while the peak radiation on the south wall was (560.7w/m2) at the same time. Figure (12) demonstrates the variation of temperature of the external layer of the south wall of the two rooms with and without PCM. From this figure, it is shown that the temperature on the wall with PCM (TW) is slightly less than that on the wall without PCM (NTW) due to the cooling effect of PCM during charging time while at discharging time, the temperature on the outer surface of TW will be more than that of NTW due to the heat released from the PCM to the surrounding during discharging time. Figure (13) demonstrates the temperature profile on both the south wall's inner surface with and without PCM. The temperature on the inner surface of the wall with PCM (TW) is less than that on the corresponding location on the wall without PCM (NTW) with (2.7°C) due to the insulation role of PCM where PCM absorb a large amount of heat during phase change so that it will increase the thermal insulation inside the wall. Also, from this figure, it can be concluded that the PCM increases the time lag by 1 hour, and that will shift the peak load where, [8]:

\[ t_l = t_p - t_s \]  

(1)

Figure (14) declares that the temperature variation of both the standard and test rooms. The peak reduction in the test room temperature was (2.7°C) compared with standard room due to the insulating effect of PCM used in TW.
Figure 10. The predicted temperature profile of Diwaniyah city in 2019.

Figure 11. Solar radiation.

Figure 12. Outer surface temperature.
5. Conclusions
The utilization of PCM as thermal insulation materials had been investigated experimentally. From the obtained results, we conclude the following points:

1) Reduction in the south wall's inner surface (TW) of the PCM room by about 2.7°C compared to the wall without PCM (NTW).
2) Reduction in the PCM room air temperature by 2.7°C compared to the standard room.
3) From the reduction in the inner temperature of the PCM wall (TW), it can be concluded that the use of PCM will lead to an increase in the stored heat in TW more than that stored in NTW, and that will cause a reduction in the heat gain entering the room.
4) Increasing time lag by 1 hour and that shifts the peak load.
Nomenclature

| Symbol | Description |
|--------|-------------|
| Amb, T | Ambient air temperature (°C) |
| tl     | Time lag (hour) |
| tp     | The time corresponding to peak temperature on ISTW (hour) |
| ts     | The time corresponding to peak temperature on ISNTW (hour) |

Abbreviation

| Abbreviation | Description |
|--------------|-------------|
| PCM          | Phase change material |
| TW           | Wall with PCM capsules (treated wall or test wall) |
| NWT          | Wall without PCM capsules (untreated wall or domestic wall) |
| OSTW         | The outer surface of the treated wall |
| OSNTW        | The outer surface of the untreated wall |
| ISTW         | The inner surface of the treated wall |
| ISNTW        | The inner surface of the untreated wall |
| ER           | Test room (room with PCM wall) |
| SR           | Standard room (room without PCM wall) |

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