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ARTICLE

Study on Phase Change Material in Grooved Bricks for Energy Efficiency of the Buildings

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ABSTRACT

Phase change materials (PCMs) are an interesting technology due to their high density and isothermal behavior during phase change. Phase change material plays a major role in the energy saving of the buildings, which is greatly aided by the incorporation of phase change material into building products such as bricks, cement, gypsum board, etc. In this study, an experiment has been conducted with three identical small chambers made up of normal, grooved and PCM-treated grooved bricks. Before the inclusion of PCM in grooved bricks, PCM material behavior has been studied by different techniques such as DSC, TG/DTA, SEM, and XRD. Thermal properties and thermal stability were investigated by differential scanning calorimeter (DSC) and thermogravimetric analyzer (TGA) respectively. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to determine the microstructure and crystalloid phase of the PCM before and after the accelerated thermal cycling test (0, 60, 120). These three identical model rooms built were exposed at a temperature just above 40 °C with a heater. When the maximum outdoor temperature was 40-41 °C, then the temperature of the PCM-treated grooved chamber was 32-33 °C. The PCM-treated wall was tested and compared with a conventional and grooved wall. The difference between the PCM-treated grooved chamber and the untreated one was 8-9 °C. PCM-treated bricks provided more efficient internal heat retention in summer when the outside temperature increased.

Keywords: Phase change material; Building temperature; Brick; Fatty acid; Cementitious materials

1. Introduction

Phase change materials are one of alternative resources for renewable energy. These materials are going to be used in building materials to delay the temperature curve in residential houses. In the

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market, plenty of phase change materials are available [1,2]. Generally, these materials are fatty acids, hydrates, and waxes [3,4]. PCM can improve thermal properties such as thermal conductivity, specific heat, and heat capacity of building materials/components [5]. Most researchers are continuing efforts on phase change materials to decrease energy demand in buildings [6-14]. Ravikumar and Srinivasan applied a phase change material into the room and compared to reinforced concrete, withering course. When withering course was laid along with reinforced concrete and withering course with PCM laid roof the heat entering the room was reduced by 46.88% and 71.16% [15]. Shilei et al. have conducted an experiment with the incorporation of PCM in wallboard and tested thermal properties of PCM with differential scanning calorimetry [16]. Pasupathy and Velraj have studied the thermal performance of an inorganic eutectic PCM-based thermal management system for thermal management in residential buildings [17]. Jin et al. analyzed a new double-layer PCM and two layers have different temperatures applied to the floor. They compared the floor without PCM, energy released by floor with PCM in peak period increased by 41.1% and 37.9% during heating and cooling when the heat of fusion of PCM was 150 kJ/kg [18]. Lai et al. studied hollow bricks with and without PCM and exposed these bricks to the solar radiation. The temperature difference between treated and untreated hollow brick was about 4.9 °C [19]. Li et al. incorporated PCM in porous network of cement composite by absorption process. Cement acted as supporting material to prevent leakage. The cement and PCM composite have the latent heat of 69.12 kJ/kg with melting temperature of 31.86 °C [20]. Zuo et al. have taken two PCMs and mixed them at different compositions i.e. eutectic. Melting temperature and latent heat of fusion were analyzed by DSC [21]. Ceron et al. have tested experimentally on incorporated PCM in tile and compared with ordinary tile. They observed that temperature difference between normal and PCM tile was 4-10 °C. They concluded that PCM was the possible solution of optimizing energy efficiency in construction [22]. In the summer season, building demands more energy because lack of advanced materials and people want live in thermal comfort zone. Researchers and technologists are attempting sophisticated materials such as extremely porous materials, vacuum insulation materials, phase change materials, etc. to reduce energy consumption in buildings. Among the advanced materials PCMs are the possible solution for reducing energy demand in the building at peak hour requirements. In this present study, PCM is incorporated into grooved brick to evaluate temperature profile and the energy efficiency of the bricks to address the above problems confronting the buildings. **Table 1** summarizes the findings of temperature/energy demand reductions afforded by the PCM with relevant literature review.

Table 1. Comparison of temperature reduction using PCM in building materials.

References	Findings
Shi et al. [23]	Energy savings can reach 10% or more throughout the winter.
Lee et al. [24]	Heat flux reductions were 29.7% and 51.3% and at the west and south wall respectively.
Kuznik and Virgone [25]	PCM room temperature is reduced to 4.2 °C.
Evers et al. [26]	Mean heat flow reduced by 1.2% and 9.2% per day.
Sharma et al. [27]	Cooling load decreased by 35.4%. Heating load reduction was 12.8% per autumn.
Mandilaras et al. [28]	The highest temperature is decreased in concrete wall to 4 °C.
Kong et al. [29]	The postponement times for maximum and minimum temperature peaks are increased to 3 hours for samples.
Cabeza et al. [30]	The highest temperature decreased by 1 °C and temperature was delayed by 6 hours.
Castell et al. [31]	Peak temperature reduced by 1 °C.
Principi and Fioretti [32]	Heat flux reduced by 25% and prolonged by 6 hours.
Banu et al. [33]	Energy saved by 79%.

Table 1 continued

References	Findings
Lai et al. [34]	The mean peak reduction was 29.1% and total reduction in heat flux was 16.3%.
Hichem et al. [35]	The temperature of the interior wall was decreased by 3.8 °C and the heat flux was lowered by 82.1%.
Ahmed et al. [36]	The highest room temperature was lowered by 2.2 °C.
Kuznik et al. [37]	Delay the heat flux was about 100 minutes.
Tiago et al. [8]	The temperature was reduced to 5 °C and approximately 3 hours delayed entering heat in the room.
Kara and Kurnucx [38]	14% of the test room's annual heat flux reduced with PCM.
Heim and Clarke [39]	Heat load reduced by up to 90% in summer season.
Kong et al. [29]	1-2 °C reduced in PCM room and wall temperature delayed to 2-3 hours.
Diaconu [40]	10 kWh of energy savings was observed in PCM incorporated system.

2. Materials and methods

The grooved bricks and normal bricks were purchased from the local brick industry of Roorkee. The PCM i.e. fatty acid (C12) purchased from Pioner Inorganics, Delhi. The details of fatty acid, which is used as PCM and their properties are presented in **Table 2**. Calibrated Chromal-Alumel (Type K) thermocouples, plastic cups, and digital temperature measurement were used in this experiment.

Table 2. Properties of PCM.

Properties	Values
PCM	fatty acid
Melting point (°C)	40
Latent heat of fusion (kJ/kg)	227.1
Thermal conductivity (W/m•K)	0.127
Density (kg/m^3)	942.7
Specific heat (kJ/kg•K)	2.3

3. Analysis of phase change materials

3.1 Differential scanning calorimeter (DSC)

The thermal properties of PCM were tested by DSC (**Figure 1**). DSC measurements were performed using a DSC7 thermal analysis system supplied by Perkins-Elmer, USA. DSC runs were carried out at a heating of 5 °C/min under constant stream of Argon atmosphere. The sample weight for PCM is approximately 2.5-10 mg [41]. The melting point temperature of PCM corresponds to the initial temperature obtained by drawing a line on the highest slope point of the upper edge. The melting point and latent heat of fusion of PCM are 40 °C and 227 kJ/kg.

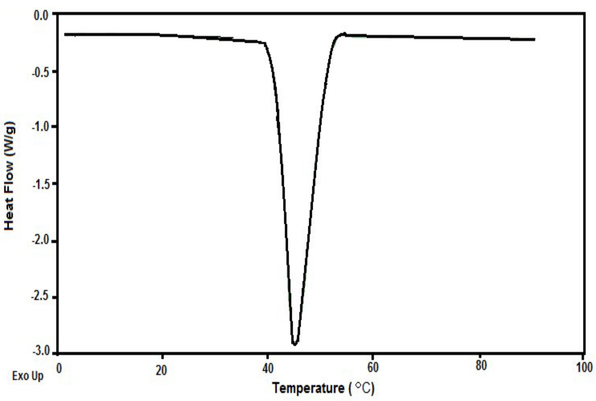


Figure 1. DSC curve of fatty acid, heating rate 5 °C/min.

3.2 Accelerated thermal cycle test

Accelerated thermal cycling tests were performed to investigate changes in melting temperature and latent heat of PCM. Thermal cycle test referred to heating up to the melting point of PCM provided in **Table 1** and then cooled to until PCM completely gets solid i.e. below the melting point. The above procedure is carried out continuously up to 60 and 120 cycles in thermal cycle chamber. After 60 and 120 cycles, DSC was performed to evaluate the melting point and latent heat of PCM. The obtained results were presented in **Table 3**.

Table 3. Melting point and heat of fusion of fatty acid after thermal cycle test.

S.No	No of Cycles	Melting Point (°C)	Heat of fusion (kJ/kg)
1	0	40	227.1
2	60	40	227
3	120	40	277

From **Table 3**, it has been observed that there are no significant values changed after 60 and 120 cycles (Zuo et al., 2011).

3.3 Thermal stability of phase change material (TGA)

The thermal stability test was performed in Thermal Gravimetric Analysis (TGA) from ambient to 40 °C (8-10 mg) in constant nitrogen vapor in the atmospheric pressure at a heating rate of 5 °C/min (**Figure 2**).

From the **Figure 2**, there is no significant weight loss observed even after 60 and 120 cycles.

3.4 Scanning electron microscopy (SEM) of PCM

The carbon tape was adhered on stub. The PCM sample was placed on carbon tape. The PCM samples were coated with gold sputter coater for conducting the PCM samples. Morphology was examined by scanning electron microscopy (SEM, OXFORD-7000F, LEO Inc. UK) to observe microstructural changes after 0, 60, and 120 cycles of PCM. The morphology of PCM changed at each cycle. This is because in each cycle phase changes i.e. solid to liquid vice versa. During these cycles, rearrangement of molecules is placed (**Figure 3**). The changes of morphology won't affect the thermal properties of PCM.

3.5 X-ray diffraction analysis of PCM

The XRD was used to observe mineralogical changes in PCM samples after 0, 60 and 120 cycles. The PCM samples were flattened on glass slide. The glass slide was kept in X-ray diffraction (XRD, Rigaku, Japan) and then XRD was operated from 0 to 60 degrees at a rate of 3 degrees/min. The peaks contained after the 0 cycle of PCM, the same intensity peaks were observed in both cycles i.e. 60 and 120 cycles. From **Figure 4**, it has been observed that there are no additional peaks.

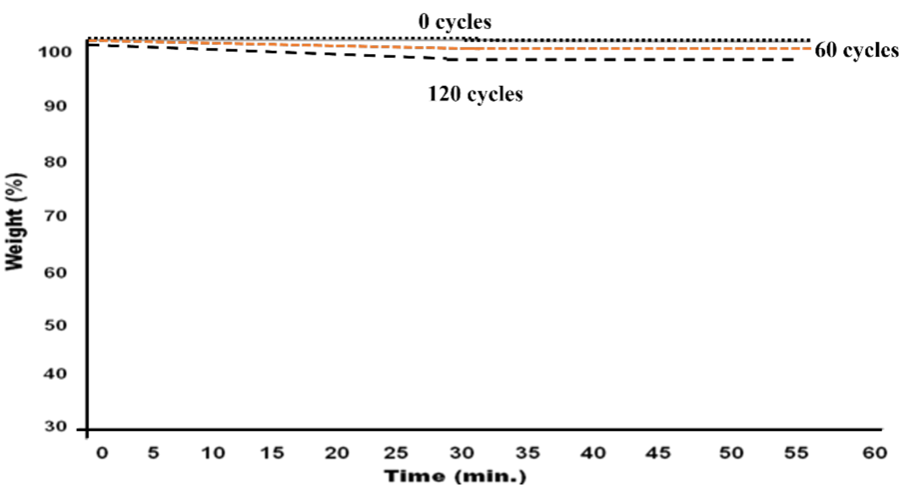
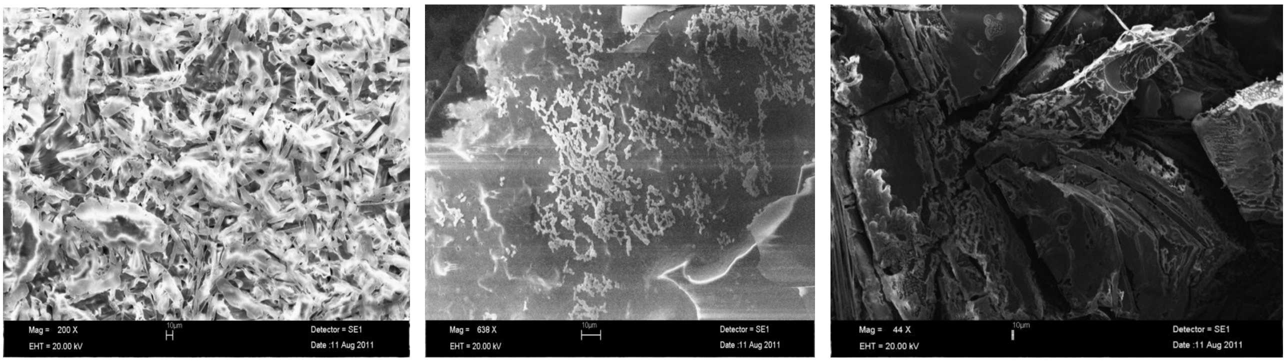


Figure 2. TGA curve of fatty acid, heating rate 5 °C/min.



(A) (B) (C)

Figure 3. Morphology of PCM (A) 0 cycle (B) 60 cycle (C) 120 cycle.

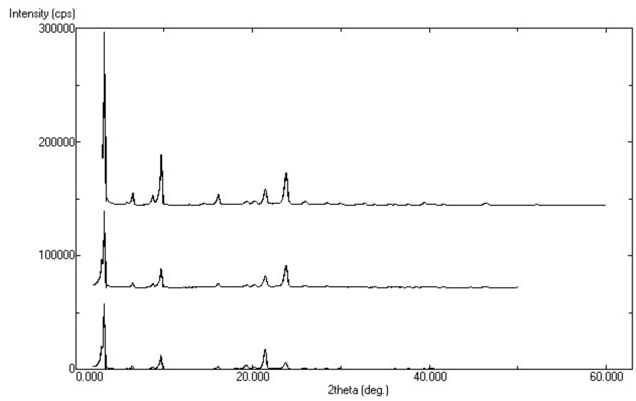


Figure 4. XRD curves of PCM.

4. Experimental

4.1 Thermo physical properties of PCM

Thermal conductivity and specific heat are the two important parameters for analyzing the energy efficiency in buildings. To determine these two properties, the following empirical equations were used. Specific heat of PCM (Cp) 2.27 J/kg•K estimated from the ROWLINSON-BONDI equation [42].

$$\rho_1 = \frac{\rho_0}{[1 + \beta(T_1 - T_2)]} \quad (1)$$

$$k = 3.56 \times 10^{-5} \times C_p(\rho^4/M)^{1/3} \quad (2)$$

Based on the above Equations (1) and (2) thermal conductivity and density of PCM were determined. The obtained data are compared with theoretical data in **Table 4**.

There are no such significant values observed in the theoretical and experimental values. These equations can be used in the modeling of prototype buildings.

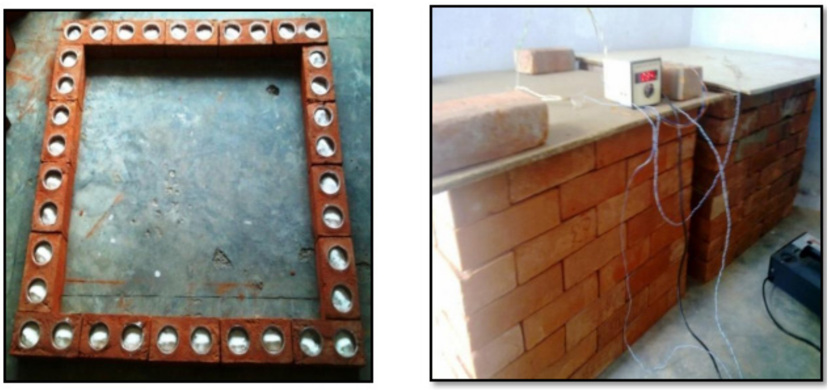
4.2 Methodology

An experiment has been conducted in a room size 662 cm × 432 cm × 700 cm with two identical walls that were ordinary, grooved and PCM-treated (**Figure 5**). The grooved and PCM incorporated brick walls were compared with ordinary wall. The walls were exposed just above 40 °C with the help of heater. The calibrated thermocouples were installed on top and bottom of the wall and measured temperature profile during 12 h. After that, the same experiment was repeated with two identical chambers constructed in a room i.e. grooved and PCM-treated.

In this experiment effect of masses (1 kg to 5 kg of PCM) varied in the grooved brick. The additional thermocouples were placed in the PCM contained chamber and measured phase change temperature from the solid to liquid and vice versa. Based on outside and inside of temperature profile of all the chambers determined heat flux of the chamber using governing equation.

Table 4. Thermal and physical properties of phase change material.

Compound	Theoretical PCM	Exp. PCM
Melting Point (°C)	----	40
Heat of Fusion (kJ/kg)	----	227
Density (kg/m^3)	941.7	942.1
Thermal Conductivity(W/m °C)	0.13	0.127
Specific heat(J/g °C)	2.27	2.286



Bricks arrangement with PCM PCM Chamber

Figure 5. Experimental setup.

5. Results and discussion

5.1 Effect of temperature on PCM thermal conductivity

Figure 6 shows thermal conductivity vs temperature when the temperature was increased thermal conductivity of PCM decreases determined according to Equation (2). Generally, thermal conductivity has descending order in material i.e. solid > liquid > gases. At 40 °C, PCM transition from a solid to a liquid state, and during this transition, PCM thermal conductivity drops. When temperature increases up to 50 and 60 °C, the thermal conductivity of PCM decreases. However, there is no such huge changes occurred in **Figure 6** as temperature changes.

5.2 Thermal analysis of ordinary brick wall

An experiment has been conducted on three walls that were normal, grooved, and incorporated PCM wall. Thermocouples were connected top and bottom surface of each wall. To increase the surface temperature just above 40 °C heater was lit on onside of the wall and generated temperature profiles were on 12 hours basis (7 a.m. to 7 p.m.). The top and bottom surfaces of a typical brick wall were shown to vary in temperature from 7 a.m. to 7 p.m., respectively, in **Figure 7**. The temperature difference within normal brick wall was quite moderate. Heat transfer takes place through the wall by conduction. Top surface of the wall temperature reached its highest point (40 °C), then the bottom surface temperature of the wall was 39 °C. Due to the wall's heat resistance, there is a 1 °C temperature difference observed between the top and bottom surfaces of the wall.

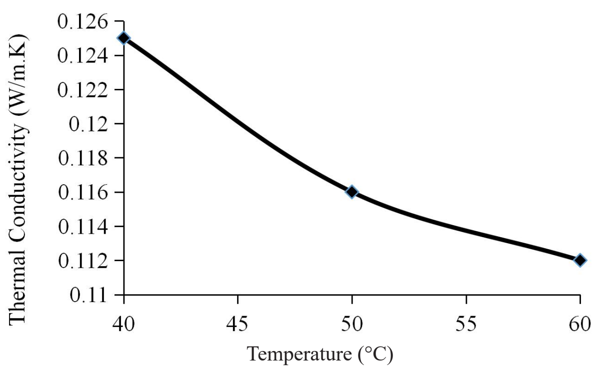


Figure 6. Temperature effect on thermal conductivity.

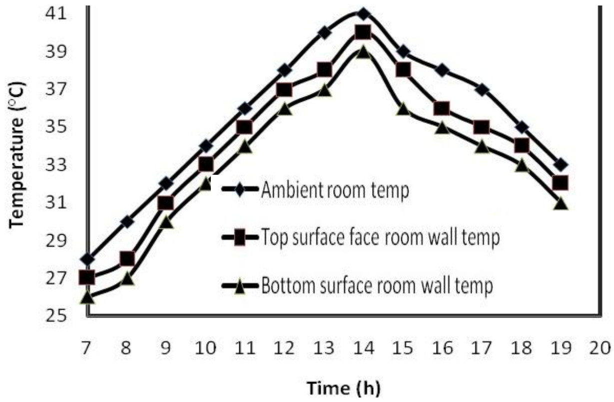


Figure 7. Temperature profile of normal brick.

5.3 Thermal analysis of grooved wall

Figure 8 depicts the top and bottom surfaces of the grooved wall's surface temperature changes from 7 a.m. to 7 p.m. From 7 a.m. to 9 p.m., there was a rather small temperature change inside the untreated bricks. The top and bottom surfaces of the bricks differed in temperature by one hour. When the wall's top surface temperature reached its peak (40 °C), the wall's bottom surface temperature was 38 °C, resulting in a temperature difference of around 2 °C because of the wall's thermal insulation capacity (which here refers to air in the center of the cylindrical holes). The temperature inside the grooved wall increased steadily with the outside temperature.

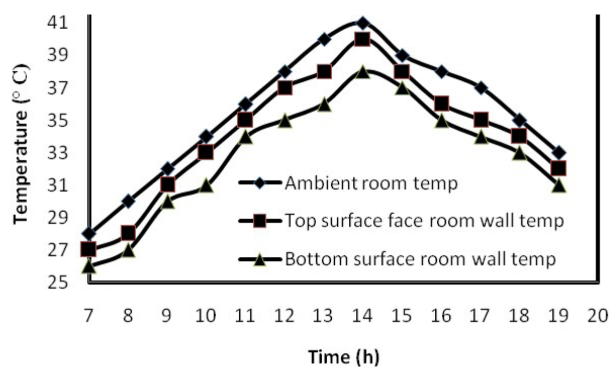


Figure 8. Temperature profile of grooved brick.

5.4 Thermal analysis of incorporated PCM wall

Figure 8 depicts the top surface and bottom surface temperatures of the PCM-treated wall from 7 a.m. to 7 p.m., respectively. Due to the presence of PCM in the wall, solid-liquid state phase shifts accounted for more of the PCM wall's thermal behavior. As heat delivered through the brick, as shown in **Figure 8**, its temperature increased to 40 °C. The PCM starts to melt as a result of heat transmission from the top surface of the bricks into the plastic cups. The brick between the PCM tubes also served as a heat conductor. The temperature of the wall's top surface reached its highest point (40 °C), while the wall's bottom surface reached 36 °C, with a temperature difference of roughly 3 to 4 °C between the two walls.

5.5 Comparison of thermal analysis of ordinary, grooved and incorporated PCM rooms

An experiment has been conducted with three identical chambers that were ordinary, grooved and incorporated PCM chambers. The size of each chamber was given in Section 5. The grooved brick chamber was filled with PCM. These three chambers were constructed in a room and used heater (Maharaja, Whiteline) to increase the ambient temperature of room and chambers were covered with insulation panel. Thermocouples were placed in each chamber and connected to digital temperature controller as shown in **Figure 5**. When ambient temperature profile varies correspondingly normal, grooved and incorporated PCM temperature varied. The ambient temperature at 40 °C, the normal room temperature was 39 °C, grooved room temp was 37 °C, and the incorporated PCM was 30-31 °C with time lag difference. The difference between normal and grooved chamber was 2 °C and difference between normal and incorporated PCM chamber was 8-9 °C. The difference between grooved and normal brick chamber was 1 °C (**Figure 9**). The temperature difference is more than the rest of brick chambers due to PCM absorbing more heat in the form latent heat of fusion and it resists the heat from outside to inside of the chamber.

5.6 Mass effect on incorporated PCM room

An experiment has been conducted with variation of different mass (1 kg to 5 kg) in PCM chamber.

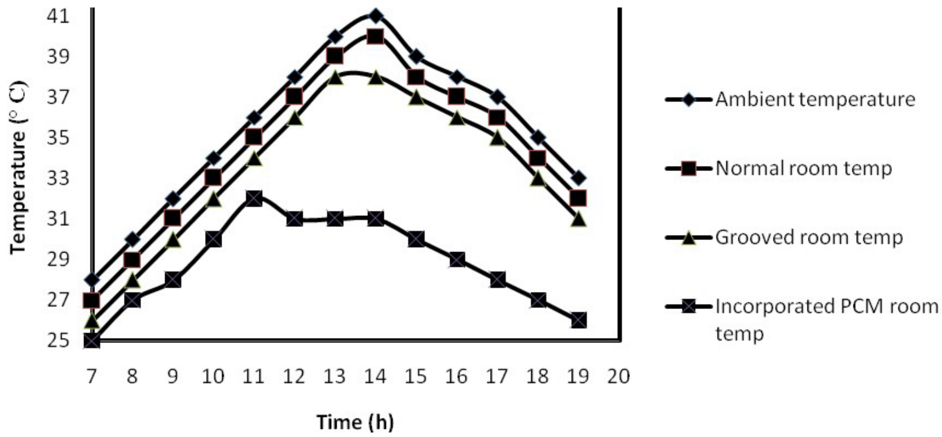


Figure 9. Temperature profile of different chambers.

The incorporated PCM chamber was exposed at 40 °C. The temperature difference of each dosage was determined with the help of data logged system. **Figure 10** shows that when mass of PCM is increased temperature difference range increased (2-11 °C) but time lag was increased due to meting out of phase change (solid to liquid) increased with respect to mass effect i.e. 1 kg to 5 kg.

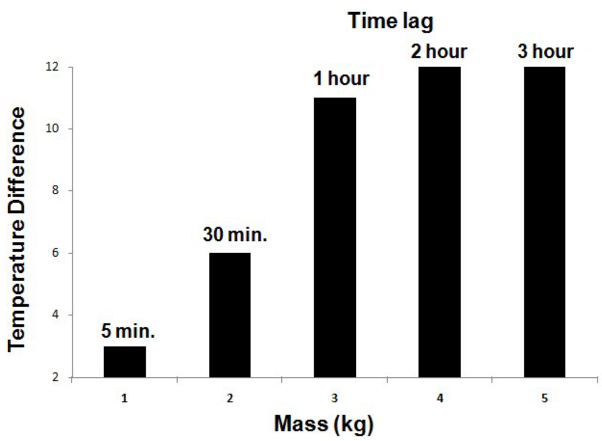


Figure 10. Effect of mass on incorporated PCM with respect to time.

When the mass is increased 1 kg, 2 kg, 3 kg, 4 kg and 5 kg corresponding to time lags are 5 min, 30 min, 1 hour, 2 hours, and 3 hours respectively. When the mass increased 1 kg, 2 kg, 3 kg, 4 kg and 5 kg corresponding to temperature difference are 3 °C, 6 °C, 11 °C, 12 °C, 12 °C respectively. At 5 kg PCM is not melted completely.

5.7 Thermal analysis of PCM

When the experimental room was exposed to the heater, and then generated temperature profile of PCM patterns (Solid to liquid vice versa). When heater was on, the temperature of PCM increased during the time 7-13 hours (**Figure 11**), this is called charging period of PCM in which PCM melts after sensible and heat is absorbed. After one hour heater was off, the temperature is decreased due to PCM going to turns its phase from liquid to solid, is called discharging period during the time 14-19 hours and absorbed heat is released to both sides of the chamber (inside and outside).

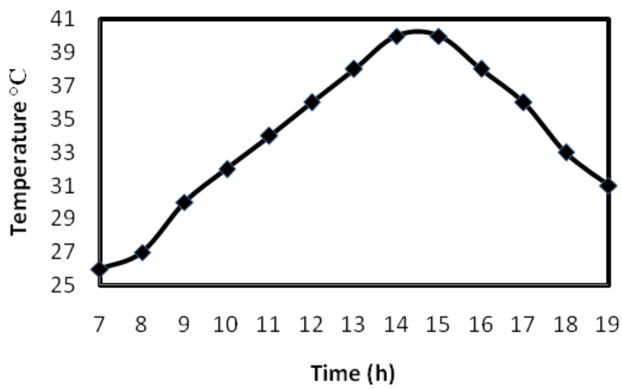


Figure 11. Temperature profile of PCM.

5.8 Heat flux entering the room

Figure 12 makes it abundantly evident that PCM applied on the brick is superior to regular, grooved brick. Heat entering the room can be decreased if PCM is mounted on the wall. Grooved and PCM walls reduce heat transfer by 49.1% and 87.3%, respectively, when compared to the standard wall. The reduction in net heat transmission to grooved walls was determined to be 38.9%. The heat flux is decreased due to absorption. Heat is more in PCM chamber than the rest of the chambers due to ordinary chamber observing the heat in the form of sensible heat, grooved brick observing the heat in the form of sensible and conventional heat, where PCM chamber absorbs the heat in the form of latent heat i.e. latent heat > sensible heat.

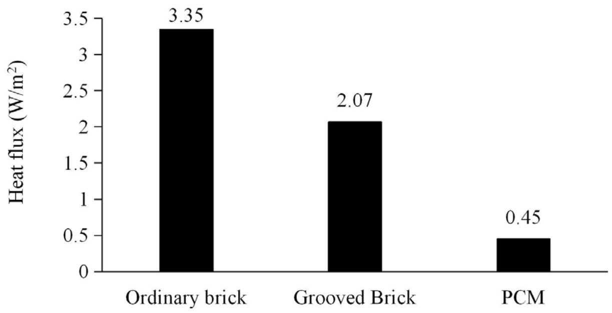


Figure 12. Heat flux entering into the room.

6. Conclusions

To reduce the energy consumption of the buildings selected a phase change material of fatty acid having the melting point of 40 °C and latent heat of fusion 227 kJ/kg. Phase change material has good thermal stability in terms of no weight loss and no changes in its melting temperature and latent heat of fusion. No Change in morphology and microstructure of PCM in its each cycle were 60 and 120. Phase change material was incorporated in grooved wall and compared with normal and grooved wall. The temperature difference of normal and PCM wall of top surfaces was equal but bottom surfaces were 2-3 °C. An experiment has been conducted in three identical rooms with normal, grooved and PCM incorporated grooved bricks. The temperature difference of normal and PCM incorporated grooved bricks room was 8-9 °C and grooved and PCM incorporated grooved bricks room was 6-8 °C at peak hour. This type of fatty acid has the potential for cool storage. PCM-treated in grooved bricks chamber had better insulation effect than ordinary and grooved bricks chamber.

Author Contributions

All authors contributed equally in terms of preparing this manuscript and performing experiments.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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