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# Experimental Assessment of Characterised PCMs for Thermal Management of Buildings in Tropical Composite Climate

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***Abstract -*** With rapid growth in urban population, there is a constraint to building space and material usage. The need is to increase the thermal mass of buildings without going back to the heavy construction used in olden days (mud houses). Thus, there is a need to build houses in small space with thin walls. The implications of building such walls is improper solar shielding increasing the inside temperatures during summer. Thus, there is a need to design a system that could result in lowering the peak temperature inside the room. The aim of this study is to test the PCM incorporated building components such as bricks and assess the temperature reduction across the same. It discusses about how phase change materials (PCMs) are competent in conserving energy in buildings through their latent heat storage capacities. PCMs are first characterised using differential scanning calorimeter to assess their thermophysical properties. The results depict the mismatch in heat storage capacity and melting temperature of PCM from as reported in the literature. The results show that with PCM incorporation there is a minimum temperature decrease of 6°C. The impact of increasing the heat capacity of the building element has also been assessed in the study.

***Keywords*:** Energy Conservation, Energy Storage, PCM, Differential Scanning Calorimeter (DSC), Thermophysical Properties, Charging-Discharging Of PCM.

## 1. Introduction

In today's world, energy utilization per capita defines economy and living standard of people within a country. Therefore, countries are now aiming at increased rate of energy production year after year. The major problem to it is the limited resources available plus they also pose a great deal of threat to our environment and health of an individual. Thus, there is an immediate need to think on the aspect of renewable sources and also conserving energy. With an aim of energy conservation in conception it is important to reduce our present energy consumption. For example, buildings alone are consuming around 48% of the total electricity produced and major share of this is used for air conditioning and domestic space heating. This variation can be reduced by using **phase change materials (PCMs)** for heating and cooling in residential and commercial buildings. PCMs capable of storing or releasing energy as latent heat thus they have high storage density. However, as each PCM has different phase change temperature, the temperature at which latent heat is absorbed or released, it is important to use an appropriate PCM for the purpose of building envelope design. This study is carried out to reduce the cooling load of buildings in tropical composite climate of Delhi, India. Aim is to utilize passive techniques for reducing the heat transfer to the building space thereby reducing the active air conditioning requirements [1].

Utilization of phase change materials for increasing the thermal mass of the building elements is one of the passive techniques being currently explored. Increasing the thermal mass with PCM incorporation serves the same purpose as thick walls in old monuments served. The temperature fluctuation within can be greatly reduced with increase in the thickness of the building walls. A number of studies [2]–[6] on PCM types, their application in buildings and properties has been carried out. Dynamic modelling for PCM incorporated building has been carried out for different seasons and directional impact has been studied by Saikia et. al. [7] and Fateh et. al. [8]. Jin et. al. [9], [10] has studied the impact of PCM location within a building wall, on PCM state and rate of heat absorbed and released during phase change. Meng et. al. [11] have studied the impact of composite PCM room in summer and winter conditions for China through TRNSYS simulation. Ascione et. al. [12] have studied the impact of PCM incorporation through experimentation and CFD modelling for Mediterranean climate. Similar studies assessing the impact of PCM incorporation in terms of energy savings for, East Tennessee [13], Netherlands

[14] have been carried out. Mavrigiannaki & Ampatzi, [15] observed load reduction with the use of latent heat storage in buildings.

Kaushik et. al. [16] studied the load levelling and heat transfer through a phase changing component material thermal storage wall/roof of an air-conditioned building. Belmonte et. al. [17] have carried out simulation studies to mark the reduction in cooling energy demands with PCM embedded construction elements. Biplab & Rakshit [18] and Han & Taylor [19] have compared the impact on thermal comfort with PCM and insulations for roofs and walls of a building. Pasupathy et. al. [20] have numerically tried to analyse the performance of PCM incorporated building roof for climatic conditions of Chennai (India), for hot and humid conditions and tried to validate his results using experimentation. Saxena et. al. [21], experimentally tried to map a suitable PCM to composite climatic condition of Delhi using **differential scanning calorimeter (DSC).** The results show that PCM application is potentially favourable however there is a need to find suitable PCMs and test them experimentally both through DSC and on application under real conditions.

Present study first tries map a suitable PCM based on its thermophysical properties, determined using DSC, and then test its real time impact on application into building elements for tropical composite climate in Delhi, India.

## 2. Mapping of PCMs

Weather & climatic condition of a particular place is characterised by solar radiation, sky condition, temperature, air humidity, precipitation and wind speed. Solar radiation on a surface depends on several other parameters such as longitude, latitude, time of day, time of the year, orientation direction of surface etc. For example, buildings on a south facing slope in Leh will receive more radiation compared to other orientations.

Table 1: Criteria for six climatic zones in India [22].

| Type | Climate | Relative humidity (%) | Mean monthly temperature (ºC) |
|---|---|---|---|
| I | **Hot and dry** | < 55 | > 30 |
| II | **Warm and humid** | > 55 | > 30 |
| III | **Moderate** | < 75 | 25 - 30 |
| IV | **Cold and cloudy** | > 55 | > 25 |
| V | **Cold and sunny** | < 55 | > 25 |
| VI | **Composite** | This applies when 6 months or more do not fall within any of the above categories | |

Based on these factors, weather and climatic condition in India is divided into six climatic zones. Table 1 gives the criteria for the division of various climatic zones. Knowing the climatic condition, it becomes easier to designate particular PCM to suit the existing daily conditions. Especially focussing the temperate regions, the heat stored in the phase change materials can be sufficiently high thereby help in keeping the conditions comfortable or in some cases at least tolerable for any person inside the room.

Identifying the climatic conditions of a particular place PCM is mapped, so that it absorbs solar energy during peak hours and reduce the inside temperature and hence the cooling load during peak load demand. Delhi lies in type-VI (composite) climatic zone. The mean average temperature in winter can be as low as 6.6°C in the month of Dec-Jan and can be as high as 40.5°C in May-June as shown is Fig. 1. The peak temperature in summer, during day is around 45°C whereas during night is around 26°C. Thus, the temperature variation within the building space is large. To reduce this temperature fluctuation within the building envelope, the thermal mass of building elements must be increased. This can be achieved by adding a PCM layer within the building elements. It is important to notice that the temperature of phase change of PCM must lie within the minimum and maximum temperature of Delhi.

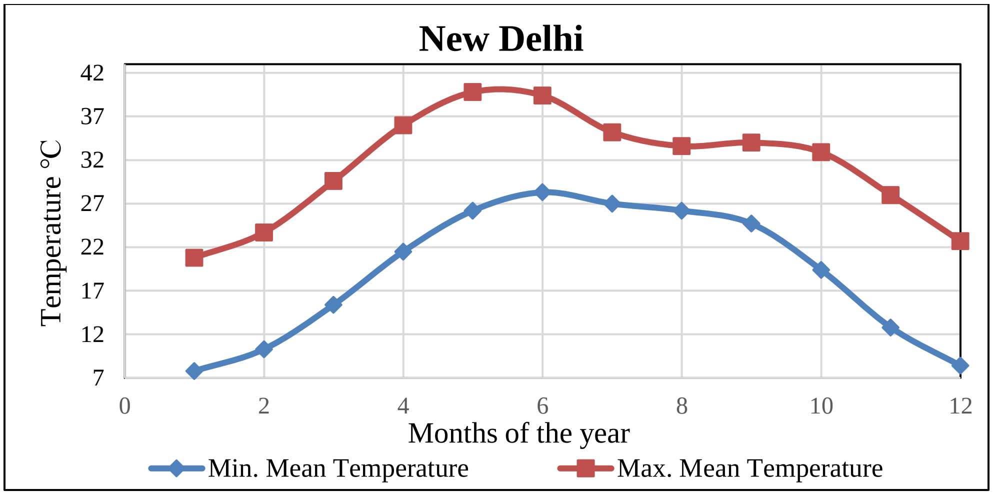

Fig. 1: Average monthly minimum and maximum temperature for New Delhi [21].

To ascertain this, two PCMs n-Eicosane and OM35 having phase change temperatures in the above temperature range, based on the literature [23], [24] have been chosen. The thermophysical properties are as shown in Table 2.

Table 2: Thermal properties of the selected PCMs.

| **PCMs** | **Nomenclature** | **Thermal Conductivity (W/mK) (solid)** | **Thermal Conductivity (W/mK) (liq.)** | **Melting temp. (ºC)** | **Cp (kJ/kg K) (solid)** | **Cp (kJ/kg K) (liq.)** | **Latent heat (kJ/kg)** | **Density (solid) kg/m3** | **Density (liq.) kg/m3** |
|---|---|---|---|---|---|---|---|---|---|
| PCM 1 | OM35 | 0.2 | 0.16 | 35 | 2.31 | 2.71 | 197 | 900 | 870 |
| PCM 2 | n-Eicosane (99% pure) | 0.39 | 0.15 | 36-38 | 1.92 | 2.46 | 247.3 | 815 | 780 |

These PCMs have been characterised using differential scanning calorimeter (DSC) to assess their sub-cooling effect (if present).

## 2.1. DSC Experiment

The heat flow analysis of PCM 1 and PCM 2 on Differential Scanning Calorimeter (DSC-Q2000, TA, New Castle, DE, USA) has been carried out. The calorimetric analysis gives the information about the charging discharging characteristics of the samples. It also gives the amount of heat absorbed and released during melting and solidification process. Thus, phase change temperature, specific heat, latent heat and degree of sub-cooling can be assessed from a DSC thermogram. The experimental temperature range was kept from 10°C to 60°C at a ramp rate of 5.0°C/min during heating and cooling. The thermal accuracy and precision of DSC are ±0.01°C and ±0.05%, respectively. PCMs are melted on a hot plate. The samples are placed in an aluminum pan (Tzero pan, no: 160217, Swiss make) with lid (Tzero lid, no: T160316, Swiss make), and the DSC experiment is conducted under high-purity nitrogen at a flow rate of 50 ml/min. The sample mass of 5.8 mg and 9 mg is measured using a precision electronic balance (GR-202, A&D, Japan) with accuracy of 0.1 mg. Fig. 2 shows the entire experimental setup of DSC, accessories and pre-processing required for DSC analysis.

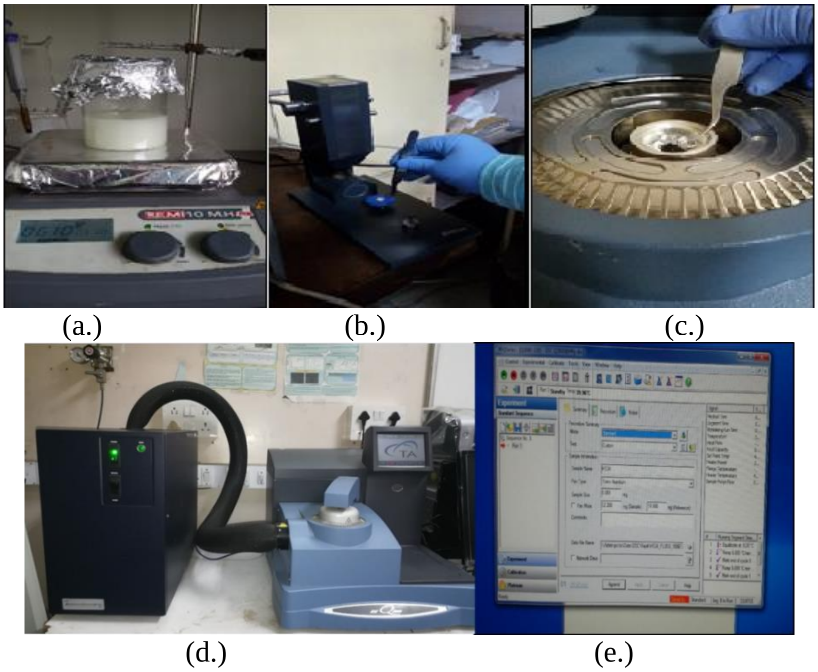


Fig. 2: (a.) PCM melting, (b.) Crimping press for PCM crimping within Tzero pan and lid, (c.) Crimped PCM sample placed in DSC cell for Testing, (d.) DSC and RCS-90, (e.) User Interface of Advantage Software v5.5.22 for data analysis.

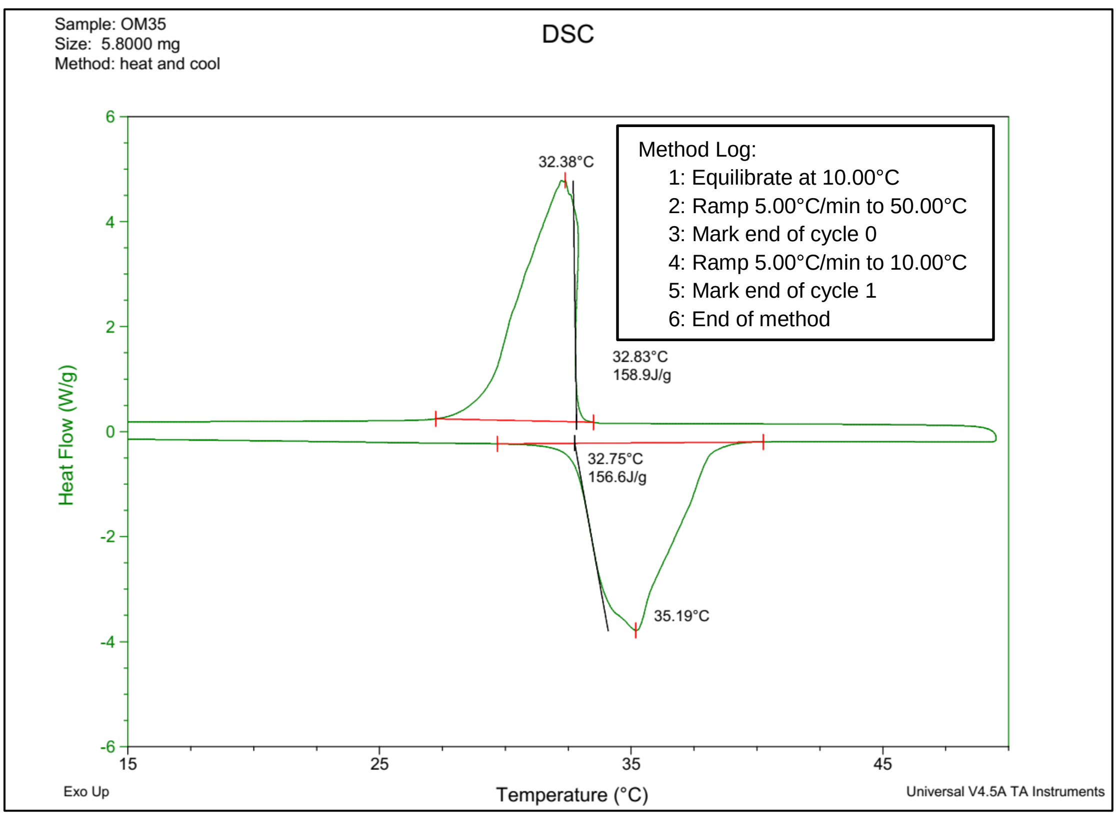


Fig. 3: Characteristic melting and solidification curve for PCM 1 (OM 35).

The DSC charging and discharging experiments are analysed using TA Universal Analysis 2000 software, for temperature range of 10°C to 55°C to assess the heat flow curve for both heating and cooling of PCMs. Fig. 3 and Fig. 4

shows the charging discharging curve of OM35 and Eicosane, respectively. Both these curve show that sub-cooling exists for both these PCMs i.e. the tendency due to which it is to be cooled below the freezing point temperature before it actually starts freezing and release energy. Around 3°C of sub-cooling exists for both these PCMs. In the case of PCM 1 it is observed that solidification of the PCM starts at 33°C and is completed at 28°C. The literature reports the solidification temperature of 34°C which is not its accurate value. The value of latent heat is also found to be inaccurate and was equal to around 157 J/g instead of 197 J/g as given in the technical document of the PCM from the manufacturer. The thermophysical properties of PCM 2 were found to be in close conformance with the values in the literature.

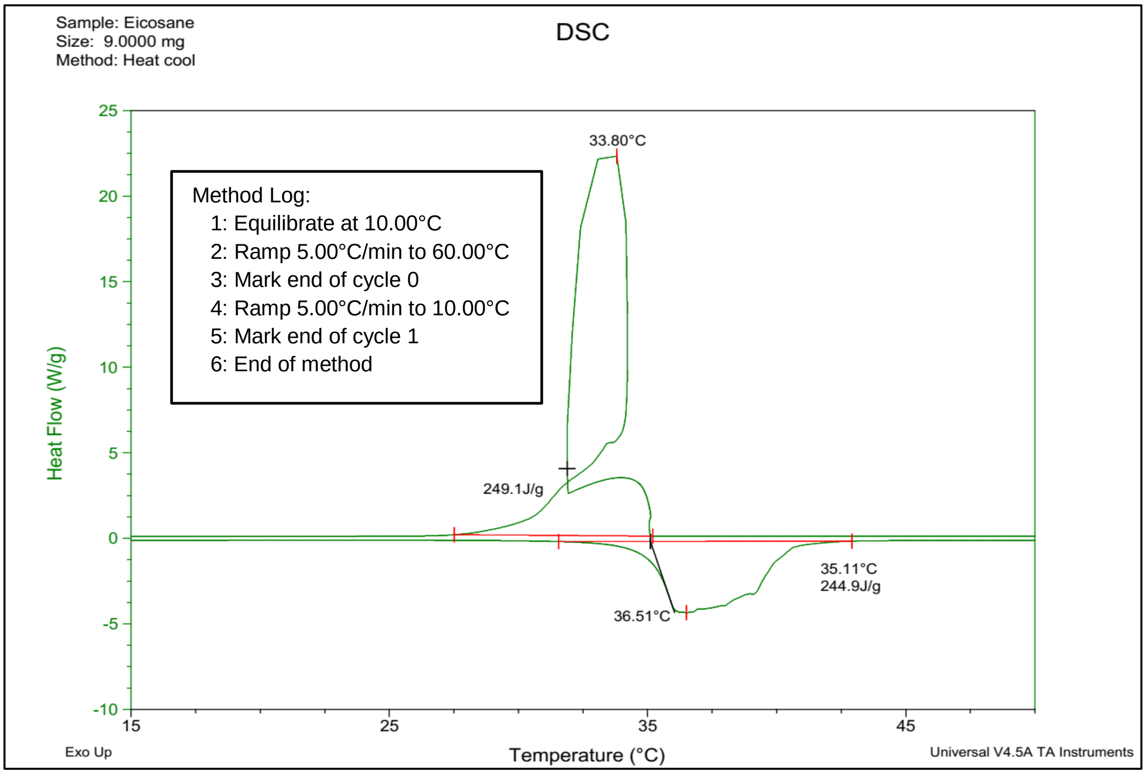

Fig. 4: Characteristic melting and solidification curve for PCM 2 (n-Eicosane).

It is clear from the charging and discharging curve of both these PCMs that their phase change temperatures lie within the minimum and maximum temperature of Delhi in summer. Thus, both these PCMs are suitable for application within the building elements.

## 3. Experimental Testing of PCM Incorporated Building Element

In literature, the anomaly between the melting and solidification temperatures have not been considered during the simulation studies carried out so far thus, there is lack of model which takes into consideration the difference between the solidification and melting temperatures during charging and discharging. Thus, experimental testing of PCMs under real conditions must be carried out to assess the actual impact of PCM incorporation within building elements which is found missing in literature for Indian conditions.

### 3.1. Geometry of the Experimental Setup

The PCM is incorporated within the specially prepared hollow bricks as shown in Fig. 5 a. with dimension of 22.5 cm x 12.5 cm x 10 cm. The PCM is kept within a casing made up of sheet metal, thickness 1mm, dimension 15.5 cm x 9 cm x 1.5 cm, as shown in Fig. 5 b. The metal casing helps in discharging process during the night as thermal conductivity of both these PCMs is low and it also provides strength and support for the hollow brick. Two identical casings are filled with 148 gm of OM35 and 141 gm of Eicosane, respectively. The macro-encapsulated PCM, shown in Fig. 5 (c.), are placed within the hollow bricks. These bricks along with a conventional brick of dimension 22.5 cm x 12.5 cm x 10 cm is placed within a wooden box covered with thick polystyrene insulation on all sides except the top surface, dimension 22.5 cm x 10 cm, exposed to sun as shown in Fig. 6. Thus, unidirectional heat flow takes place through 2 cm thin layer of brick followed by 2 mm sheet metal layer then PCM, followed by sheet metal then again brick. During the day when solar radiation falls over the brick surface, solar air temperature is generated which increases the surface temperature higher than the ambient temperature. This temperature difference between the outside and inside surface temperature acts as the driving potential for heat transfer to take place.

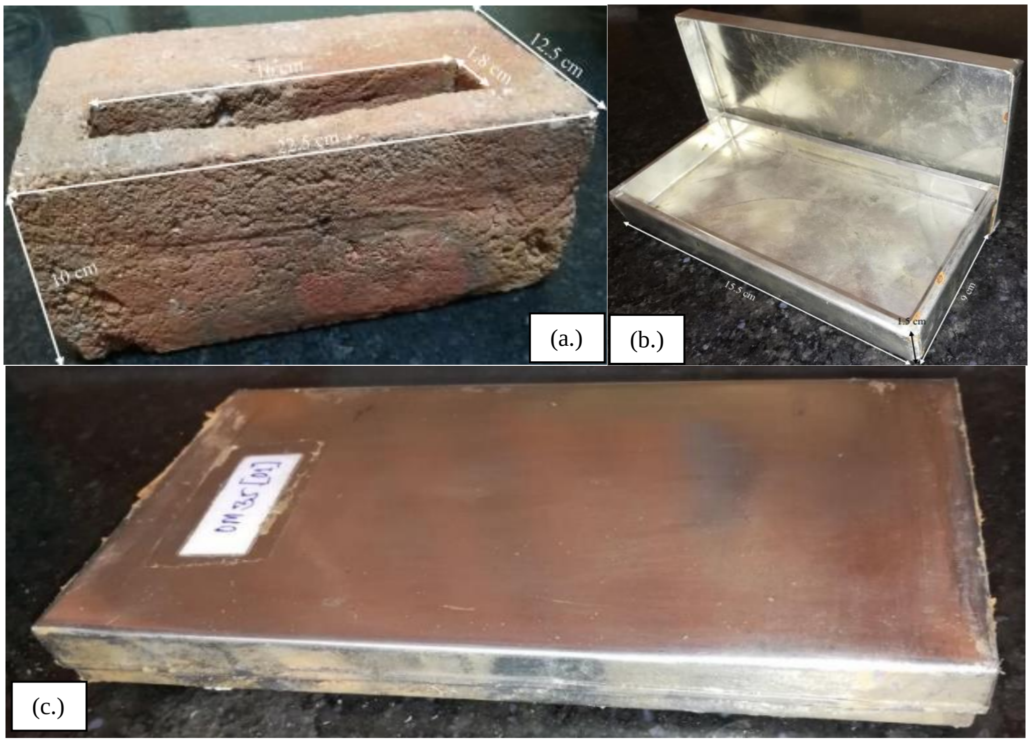


Fig. 5: (a.): Modified hollow brick; (b.): PCM encapsulating sheet metal casing; (c.): Macro-encapsulated PCM

The temperature drop across this composite brick and a normal brick is measured using different sets of ‘k’ type thermocouples and data was stored every 5 minutes using 16 channel data-logger (National Instruments) for 48 hours starting 6 am on 14$^{th}$ to 6 am on 16$^{th}$ of May, 2018 at roof top Centre for Energy Studies, IIT Delhi, New Delhi.

Fig. 6: Experimental Setup.

## 4. Results and Discussion

Fig. 7 shows the comparison of outside and inside surface temperature of the bricks. It is observed that the inside surface temperature of the normal brick rises faster than the modified PCM incorporated bricks. It is clearly observed that peak temperature reached in both the PCM bricks is less than by around 7°C on day one i.e. on 14th May and around 6°C on day two i.e. 15th May. The minimum temperature attained in normal brick is around 25°C and 22°C on day one and day two, respectively. Whereas, for PCM bricks the minimum inside surface temperature was 26°C for day one however for day two the temperature fell to 24°C due to early morning shower. Thus, it is noticed that temperature fluctuation in PCM incorporated brick is less as compared to normal brick. The overall temperature fluctuation reduces with increase in thermal mass of the building component. Fig. 8 shows the comparison of the PCM temperatures and its variation. It can be seen that temperature in both the cases rises above the phase change temperature during the day and is cooled below it sub-cooling temperature during the night.

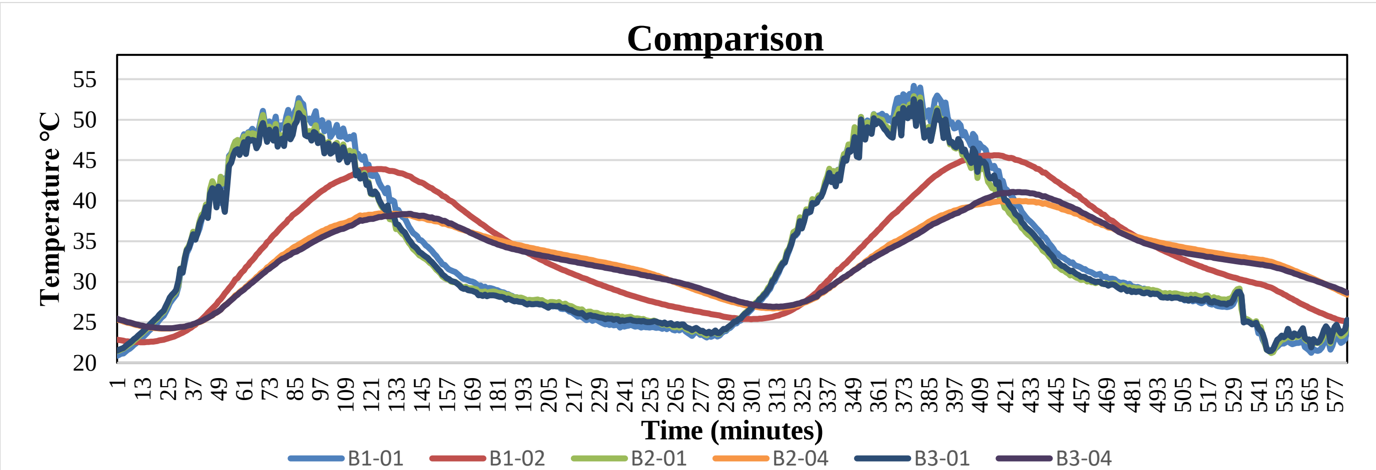


Fig. 7: Comparison of conventional and PCM incorporated bricks.

Thus, it is evident that effective charging and discharging of PCMs takes place for both these PCMs on daily basis which ensures the effective utilization of these PCMs. It is further observed that with the increase in latent heat capacity of the PCM the peak temperature achieved by the PCM also decreases i.e. in the case of OM35 the peak temperature attained is 42.2°C whereas in the case of Eicosane the temperature is restricted to 39.8°C.

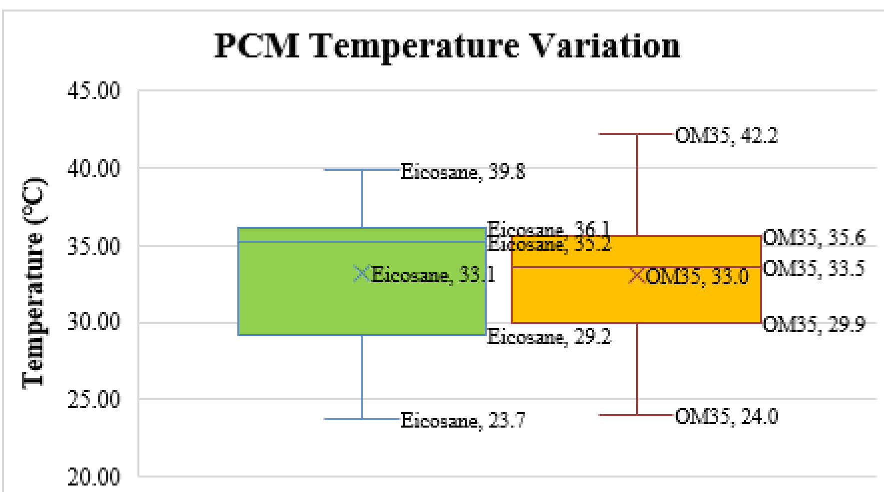


Fig. 8: Comparison of PCM temperature.

Thus, it is implied that PCM incorporation not only reduces the peak temperature achieved but with the increase in latent heat capacity the peak temperature achieved is also reduced. The mean temperature value of both the PCMs is around 33°C however, the median for Eicosane is slightly higher i.e. 35.2°C than OM35 which is 33.5°C because of the higher melting temperature of Eicosane.

## 4. Conclusion

Following inferences are drawn from the present study:

1.Both OM35 and Eicosane are found suitable for application during summer season in Delhi as they are completely discharged during the night thus ensuring effective utilization of these PCMs.

2.The temperature decrease of around 6°C is achieved, with the incorporation of selected PCMs, on the peak inside surface temperature.

3.The value of latent heat capacity for PCM 1 (OM35) is found to be around 157 J/g and temperature range of solidification starting at 32°C and completing at 28°C.

4.It is observed that with PCM incorporation the amplitude of temperature fluctuation decreases. It is also observed that with the increase in latent heat capacity of PCM the peak temperature reached is also reduced as in the case of PCM 2 (Eicosane).

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