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# Experimental Analysis of Thermal Behaviour of Phase Change Materials in Cooling Applications of Roof Top Building Slabs

K. Pavan Kumar Reddy[1], B. Nageswara Rao[2,*], J. Pavanu Sai[3]

***Abstract***

*In this research article, different phase change materials are incorporated inside the slabs to reduce the heat transfer from the roof. Experiments are conducted during summer season March 2021 to the time lag decrement factor and heat flux to that of results are compared with RCC slab to that of Green material I (CaCl26H2O) and Green Roof with Green material II (48%CaCl2+4.3%NaCl+0.4%KCl+47.3%H2O). On comparison Green Slab II is having better thermal performance over the other PCM materials incorporated in building slabs. The time lag and decrement factor are found to be 4 and 0.485 for Green roof II which is better than the other slabs. The percentage of error is found to be 0-5% for experimental and Analytical comparison for each slab which is a good sign for its thermal behavior. On average the temperature inside the slab is in between 2°C to 8°C for Green Roof II which is a good sign over the other slabs used for comparison. The heat flux is also reduced to 65% to 70% for the month of March 2021 by using Green Roof II. The novelty of this research work is to reduce the heat entering inside the building during summer season for Anantapur region by incorporating PCM materials inside the slabs as it is the second highest temperature receiving area in India. Unsteady state heat transfer calculations are also done for comparison of different slabs at this location.*

**Keywords:** PCM efficiency, Application of Cooling, Phase Change materials, Melting temperature, PCM in budlings.

## INTRODUCTION

The introduction clearly states the object of your work, its scope and the main advances you are reporting. It gives reference to relevant results of previously published work. A theoretical and experimental methods section gives sufficient information about the research carried out by the researcher. The results and discussion section states your results and their potential implications. In the discussion you should state the impact of your results compared with recent work.

The references in the paper should be cited according to the Vancouver/Numbered style. Reference citation should be always in square brackets and before the punctuation [1]. The references should be arranged in proper numeral [2] sequence.

The loads for space heating and space cooling in buildings are strongly influenced by building slabs.

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As a result, by improving thermal efficiency of slabs, the structure can consume less energy. By adding extra insulation is the method most frequently utilized to improve thermal efficiency of building slabs. This may not ever be feasible due to restrictions on slab thickness or for financial reasons. Increasing the slab's potential to store energy is an alternate method to improve its thermal performance. This provides better building slab heat energy transformation, which reduces energy utilization and improves human solace, and increases the operational existence of equipment [1].

Basically there are two most important heat storage techniques categorised as constant temperature storage and temperature difference storage methods. In contrast to temperature difference heat energy storage, which increases temperature to store heat, latent heat storage devices use phase transitions to do so. Engineered compounds known as phase change materials (PCMs) change phase depending on the application and are used to store heat. It is commonly known that PCMs have a reasonably more heat density holding capacity while using less material overall in terms of mass and volume [2,3]. Building slabs with PCM integration have so attracted more attention in an effort to lower building heat energy consumption and improve occupant comfort [4].

There is much of research on the thermal efficiency of slabs that have PCM integration [5–21]. The findings from these studies are outlined below: PCM-enhanced slabs demonstrated (a) a depletion in crest heat flow cross section of the slab, (b) a temporal delay associated to the peak thermal loads, and (c) a reduction in inside temperature swings when compared to slabs without PCMs. In fact, PCM placement within the slabs is essential for the building to operate at its best since, PCMs have different melting temperatures scale and different temperatures contours over the slabs
.

It was imperative to analyze the influence of PCM position inside the slab and to determine ideal location for PCM layer, the thermal staging of slab and to determine the ideal location for this PCM slices, the thermal staging of slab furnished with PCM thermal shields. In this study, a simulator software is handling the thermal analysis.

There is a need to focus on influence of PCMs behavior through thermal analysis in this direction, the factors like time lag, decrement factor, ceiling temperatures along with internal air fluctuations are determined by using Thermal Laser Gun and Hygrometer The results are compared by using Ansys software in this study.

## PROBLEM IDENTIFICATION AND POSSIBLE RECOMMENDATIONS

A variety of issues, including excessive bulk and unfavorable temperature excursions during and after extended periods of high and low ambient temperatures, can arise from the use of stone or masonry in modern buildings. As ourselves we are Indians and our lands pass through the tropic of cancer, and we will not be able to with stand to too hot and too cold climatic conditions. Due to the abnormal temperatures will not be comfortable in these climatic conditions.

For a very long time, scientists have been investigating the technology that may be utilised to store significant amounts of cold or heat in a certain dimension of material[23]. Due to the climate in India, cooling buildings uses a significant amount of energy. Since ancient times, sensible heat storage has been utilised to combat these issues.

Latent heat storage in a phase change material is particularly attractive because of its high energy storage and isothermal phase change behaviour. Thermal storage plays a significant role in the prevention of phase change heat storage in buildings.

Increasing a building's thermal storage capacity can increase occupant comfort by lowering temperature of internal air frequency variations, bringing internal room air temperature closer to the target temperature for a longer period of time.

 

The transmission of heat in to the PCM room is reduced by 73.1 % [22] which is a direct saving in energy consumption and reduction in cooling load in case of an air-conditioned room.

## TEST RELATED SETUP

### Materials

In the present study, the phase change materials chosen are CaCl26H2O and 48%CaCl2+4.3%NaCl+0.4KCl+47.3%H2O, which are inorganic salts, are widely utilized for thermal uses in buildings comfort and has desired melting temperature, strong thermal stability, and widespread use. Due to its compatible melting, long-lasting thermal stability, and maximum working temperature, these PCM materials are chosen.

Following are the suggested names for synthetically made materials:

3Green material I = CaCl26H2O

Green material II = 48%CaCl2+4.3%NaCl+0.4%KCl+47.3%H2O

Stage I Stage II Stage III

**Figure 1.** Stage I, II, III Shows the Construction of Slab with PCM Materials.

This PCMS are encapsulated within the slab with the help of polythene cover shown in Figure 1. The required thickness of the roof slab is not compromised by the storage of the PCM panels. Under the same climatic circumstances, Examined and contrasted are the thermal capabilities of the building with a non-PCM roof. Temperature scanners and thermocouples are used in conjunction to monitor temperature differences throughout interior of the building and on the roof. During summer, when the temperatures are at peak, experimental analyses are conducted. The next part provides a description of the extensive experimental and numerical studies that were used in this work.

### Phase-Change Substance

The two PCMs such as Green material I and Green material II are received from the Vatjat Pharma Foods Private Limited-India. In our chemistry lab at SVIT we mixed 4 moles of water is added to CaCl22H2O, to change from CaCl22H2O to CaCl26H2O. Table 1 lists the significant thermophysical characteristics of Green material I and Green material II phase change materials.

The PCM absorbs the heat energy from the solar dissipation on slab surface as latent heat, which slows down the rate of heat transmission into the building interior. The PCM gains more heat during the daylight and stores energy as liquid. Due to the lower outer surface temperature at night, PCM liberates heat energy it has acquired and takes on solid form. One cycle describes this solid-liquid-solid phase transition. At a temperature range of 29-30°C and 26.5–28°C for PCM Green material I and Green material II, phase shift transition occurs periodically.

### PCM Slab Construction

The PCMs were incorporated into the wall systems in earlier experimental works using plasterboard [5,16], wallboard [7,11,14,18], exterior brick [8, 12, 19], or the insulation cavity [9,13,20]. Evers et al.

 

[9] integrated the PCM into the insulation cavity by mixing it with the cellulose insulation already present. Medina et al. [13] and Zhang et al. [20] the wall surrounding layer in touch with the conditioned area, the inner surface of the internal wallboard, was where the PCM was mounted. In present work we constructed 4 rooms with slabs. The first slab is constructed with RCC with the dimension of 120 × 120 × 120 $cm^3$. Similarly remaining two slabs also constructed with same dimensions but in between RCC slab we incorporated two different PCM materials (Green material II), This is the novelty of my work show in Figure 2 and Figure 3. Remaining slab is constructed with green roof, bottom of slab with RCC, middle portion with red soil and on its top green grass is grown show in Figure 4 and Figure 5.

**Table 1.** Phase Change Materials Thermal Properties.

| PCM | PCM (Chemical Formula) | Properties |
|---|---|---|
| I | $CaCl_26H_2O$ | 1. Appearance–Grey (Colour)<br>2. Phase Change Temperature-29°C<br>3. Density–1500 kg/$m^3$<br>4. Latent heat of fusion-188 kJ/kg<br>5. Thermal Conductivity:<br>Solid (0–29)°C: 1.09 W/m K<br>Liquid (29–60)°C: 0.54 W/m K<br>6. Specific heat<br>(0–29)°C: 1440 J/Kg K<br>(29–30)°C: 125000 J/Kg K<br>(30–60)°C: 1440 J/Kg K |
| II | $48\%CaCl_{2+}4.3\%NaCl+0.4KCl+47.3\%H_2O$ | 1. Appearance–Grey (Colour)<br>2. Phase Change Temperature-26–28°C<br>3. Density–1640 kg/$m^3$<br>4. Latent heat of fusion-188 kJ/kg<br>5. Thermal Conductivity:<br>Solid (0–27)°C: 1.09 W/m K<br>Liquid (29–60)°C: 0.54 W/m K<br>6. Specific heat<br>(0–26.5)°C: 1440 J/Kg K<br>(26.5–28)°C: 125000 J/Kg K<br>(28–60)°C: 1440 J/Kg K |

## A Test-based Setup

Four identical rooms with interior sizes of 120 cm in length, 120 cm in width, and 120 cm in height are constructed in order to study the effects of the thermal characteristics of PCMs used in buildings. These rooms have sidewalls that are approximately 10.16 cm thick. In order to compare the thermal properties of the PCM-enabled room with those of the non-PCM enabled roof and the green mounted roof, two of the building's roof slabs for these four equivalent rooms are built with encapsulated PCM panels. RCC roof slabs that are approximately 11 cm thick cover all four of the rooms.

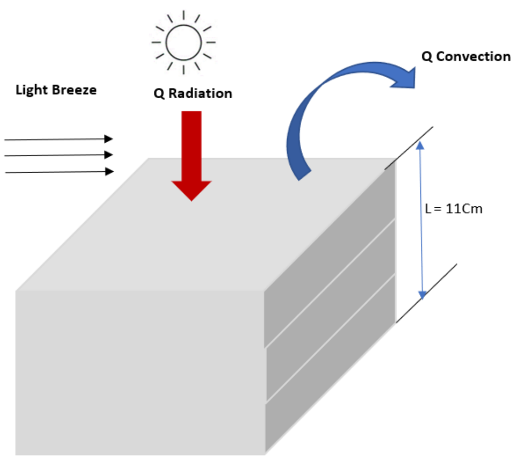


**Figure 2.** Construction of RCC Slab.

 

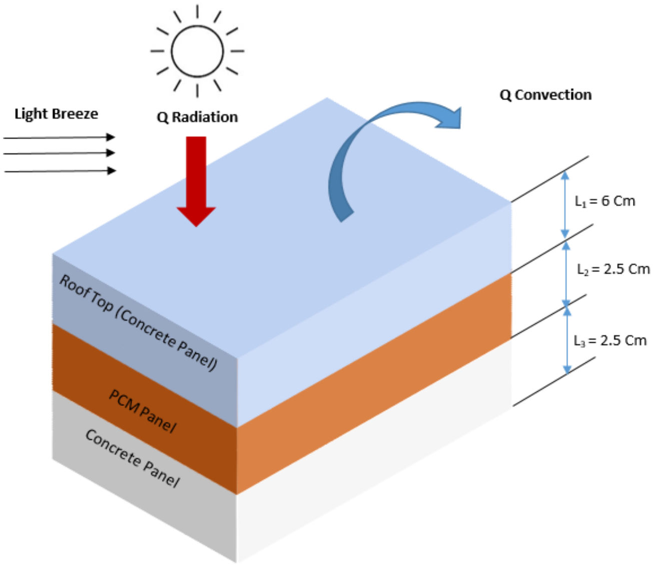


**Figure 3.** Construction of PCM Slab (Green material I) with both side Concrete Panel.

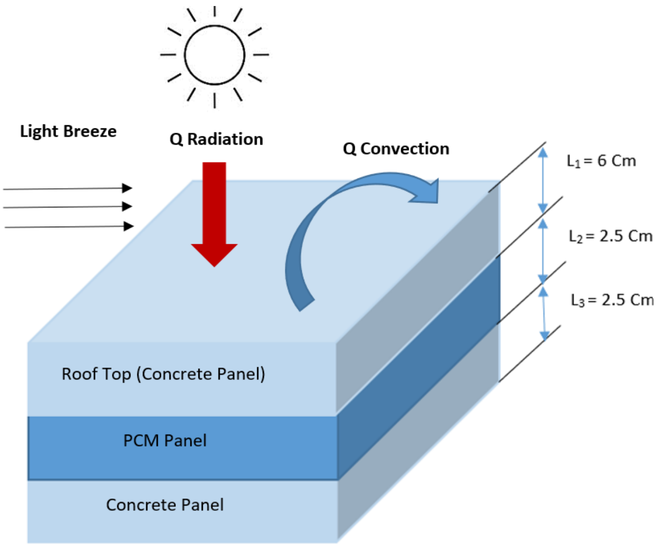


**Figure 4. Construction of PCM Slab (Green material II) with both side Concrete Panel.**

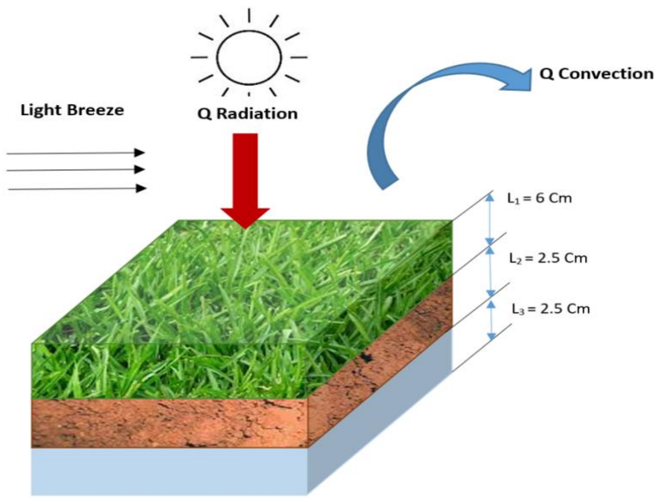


**Figure 5.** Construction of Green Roof.

 

**Figure 6.** PCM Slabs Used for Experimentation.

To investigate the impacts of the thermal properties of PCMs used in buildings, four identical rooms with internal dimensions of 120 cm in length, 120 cm in width, and 120 cm in height are built. The sidewall thickness of these rooms is around 10.16 cm. Out of these four comparable rooms, two of the building's roof slabs are constructed with encapsulated PCM panels in order to compare the thermal characteristics of the PCM-enabled room with those of the non-PCM enabled roof and the green mounted roof. All four rooms are covered with RCC roof slabs that are approximately 11 cm thick.

The four roof slabs consists of length 120 cm, width 120 cm and thickness of 11 cm. In that RCC slab contains dimensions of 11 cm thickness but whereas PCM's roofs slab are divided into layers with dimensions 6 cm, 2.5 cm and 2.5 cm respectively as shown in Figure 6. Also green roof thickness is divided into three layers 6 cm, 2.5 cm and 2.5 cm as shown in Figure 6.

The total holding capacity of PCM (Green material I) is 55.74 kgs in the thickness of 2.5 cm and for PCM (Green material II) is 60.94 kg. We have selected two types of thermal indicators for temperature readings. First one lasergun type indicator and second one is hygrometer. Laser gun type indicator is used for measuring roof and ceiling temperature of slab whereas hygrometer is used for measuring air temperature inside and outside the room. The experimental data is documented for 24 hrs from March 1st to March 31st, 2021.

**Experimental Approach**

We have conducted the experiment by taking temperature readings on top and ceiling of the roof at five nodes by using laser gun and hygrometer. This experiment is repeated for four slabs per hour on 24 hr basis. We have conducted the experiments from March 1st to 31st, 2021 for the duration of one month on 24 hr basis to calculate time lag ($\varphi$), decrement factor ($f$) and heat flux for different materials show in Table 2. The time lag ($\varphi$) is heat storing capacity of the slab in terms of time shown in equation (1). The decrement factor (f) is the percentage of the maximum heat flow out of the element's exterior surface to the steady state heat flow through the element per unit degree of temperature difference between the internal and external ambient temperatures, as shown in equation (2). The contrasting temperatures (ΔT) between the outer and inner roof surface (To) and (Ti) may be used to calculate heat flow (q) show in Figure 7.

$$\varphi = t_{T_i^{max}} > t_{T_o^{max}} = t_{T_i^{max}} - t_{T_o^{max}} \tag{1}$$

$$f = \frac{T_i^{max} - T_i^{min}}{T_o^{max} - T_o^{min}} \tag{2}$$

$$q = \frac{Q}{A} = \frac{\Delta T}{RXA} = \frac{To - Ti}{RXA} \tag{3}$$

Figures 8–10 graphs are drawn for Ceiling temperature of four rooms, temperature vs hours and results are compared. The graphs are drawn for fourth week of March 2021 that is from $22^{nd}$-$24^{th}$.

PCM (Green material II) is having better thermal performance when compared to RCC, PCM (Green material I) and green roof.

 

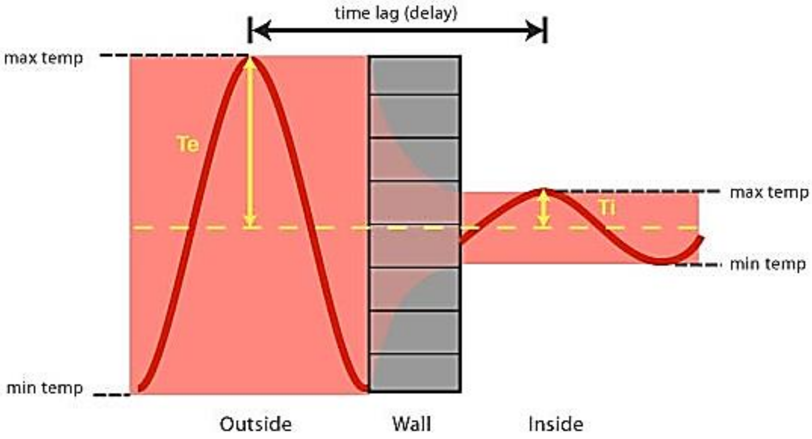


**Figure 7.** The degradation factor and time lag distribution.

**Table 2.** Roof material time lag and decrement factors.

| S.N. | Roof Material | Time lag (hr) | Decrement Factor |
|---|---|---|---|
| 1 | RCC | 9 | 0.879 |
| 2 | PCM (Green material I) | 5 | 0.682 |
| 3 | PCM (Green material II) | 4 | 0.485 |
| 4 | GREEN ROOF | 5 | 0.652 |

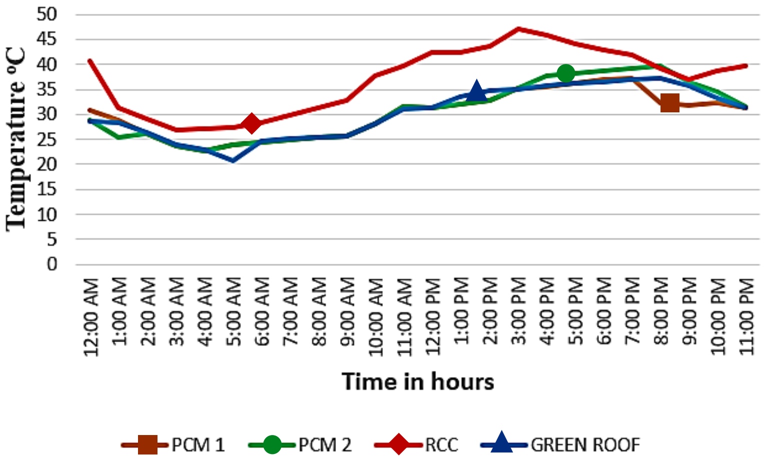


**Figure 8.** Temp for the room ceiling on March 22, 2021, shown against time in hours.

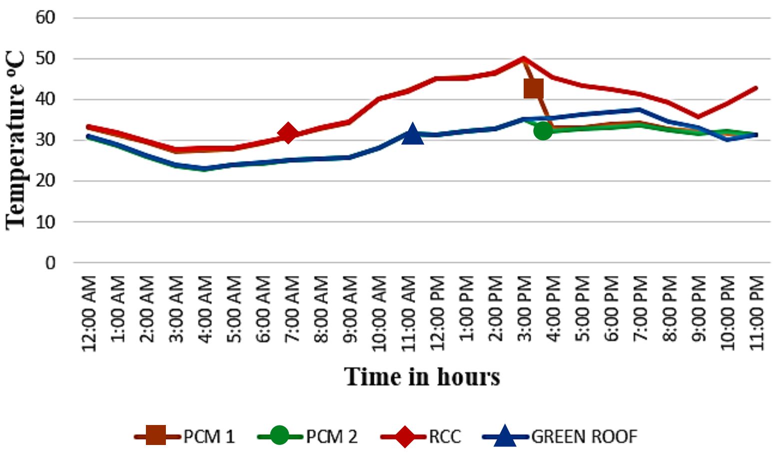


**Figure 9.** Temp for the room ceiling on March 23, 2021, shown against time in hours.

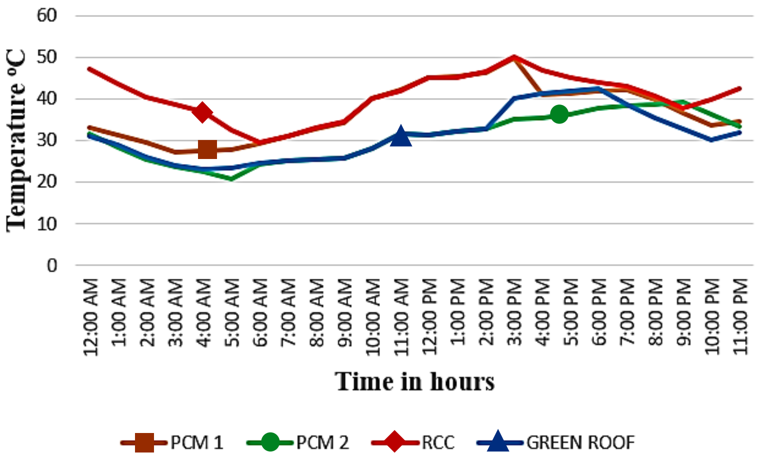


**Figure 10.** Temp for the room ceiling on March 24, 2021, shown against time in hours.

Figures 11–13 Graphs are drawn for air temperature of four rooms, temperature vs hours and results are compared. The graphs are drawn for fourth week of March 2021 that is from 22nd-24th.

PCM (Green material II) is having better thermal performance when compared to RCC, PCM (Green material I) and green roof.

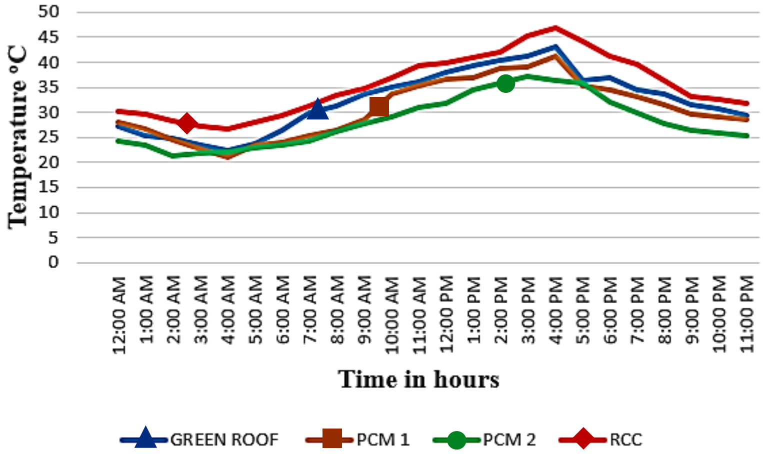


**Figure 11.** Temp vs. Time in hours for the inner room temperature on March 22, 2021.

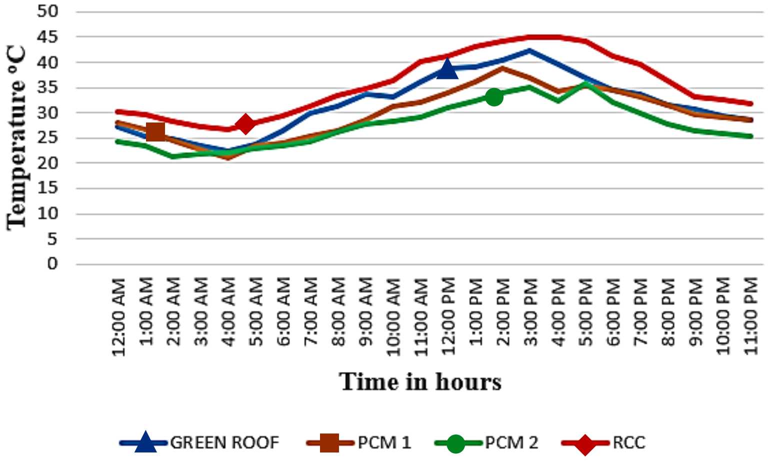


**Figure 12.** Temp vs. Time in hours for the inner room temperature on March 23, 2021.

 

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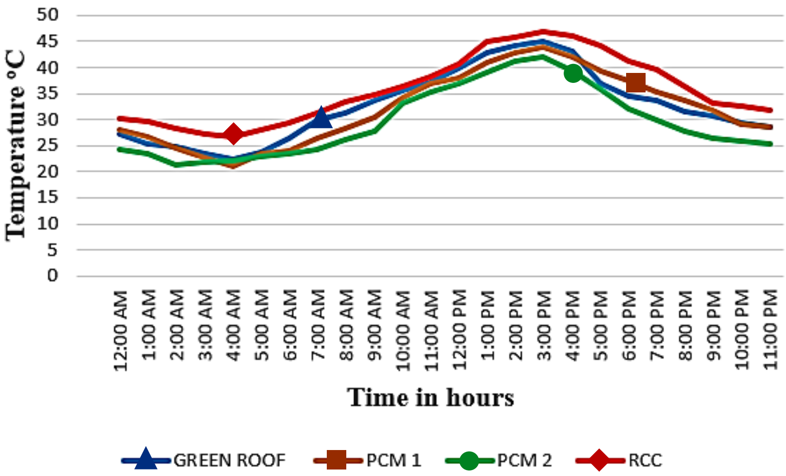



**Figure 13.** Temp vs. Time in hours for the inner room temperature on March 24, 2021.

## NUMERICAL ANALYSIS

The unsteady state thermal analysis for the roofs with RCC, PCM(Green material I), PCM (Green material II )is carried out. The PCM encapsulation panels, RCC roof slabs, and concreted lids for the PCM panels' closures make up the model. Each PCM included in the model is given the necessary thermophysical characteristics as indicated in Table.1. The temperature of the outer roof surface is provided as an input parameter throughout the simulation of both roofs in order to analyse the experimental work. The following list of assumptions underlies the current numerical model:

i. A 3D heat conduction model is used to numerically simulate the composite roof.
ii. The lateral surfaces surrounding the roof are considered to be adiabatic since the surfaces of the roof, with the exception of the top and bottom, demonstrate little heat transmission.
iii. The materials' thermal conductivity is constant and does not change with temperature.
iv. The isotropic and homogeneous PCM utilized in the roof.
v. Convective heat transmission has very little impact on liquid PCM (in the molten state).
vi. Concrete and PCM thermal expansion is not taken into account.
vii. There is very little thermal resistance at the layer interface.

In general, the PCM undergoes phase change across a given temperature range, but the specific heat value remains relatively constant. The phase transition process is thought to happen within a narrower temperature range between To and Ti for the sake of numerical simulation. Thus, the procedure for the solar radiation passing through wall/Roof (QSR), it is the radiation gained by the space when the direct sun rays passing through roof as shown in Equation (4)

$$QSR = ( UA(T_{Sol} - T_i) + UAf(T_{tSol} - T_i)) \quad (4)$$

Where Sol air temperature is denoted as $T_{tSol}$

$$T_{sol}=T_a+\frac{\beta I_{TS}}{h_o} \quad (5)$$

The Total irradiation on the roof/wall $I_{TS}$ is given as

$$I_{TS} = I_D + I_d + I_r \quad (6)$$

Where ground reflected radiation through roof/wall as $I_r$

$$I_r = CI_{DN}\rho_g\frac{1-\sin k}{2} \quad (7)$$

Diffuse radiation from the sky is given in equation $I_d$

$$I_d = CI_{DN}\frac{1-\sin k}{2} \quad (8)$$

Intensity of direct radiation is given as $I_D$

$$I_D = I_{DN}\cos\theta \tag{9}$$

Where direct normal irradiance $I_{DN}$ is given in Equation

$$I_{DN} = A\exp^{\left(\frac{-B}{\sin\beta}\right)} \tag{10}$$

Where A-Atmospheric extinction coefficient B, C are constants

The values A, B and C obtained for predicting hourly solar radiation in India[23].

$$\cos\theta = \cos\beta\cos\gamma\cos k - \sin\beta\sin k \tag{11}$$

where surface solar azimuth angle is denoted as $\gamma$ as computed as

$$(\gamma) = \phi \tag{12}$$

The solar azimuth angle is the angle in the horizontal plane measure from south to the horizontal projection of the sun's rays is shown in equation (13)

$$\cos\phi = \frac{\sin\beta\sin l - \sin d}{\cos\beta\cos l} \tag{13}$$

where altitude angle is denoted as (β)

$$\sin\beta = \cos l\cos d\cos h + \sin l\sin d \tag{14}$$

The sun declination is denoted as (d)

$$d = 23.45 sin\frac{360(284+n)}{365} \tag{15}$$

The hour angle is expressing the time of the day with respect to solar noon is shown in equation (16)

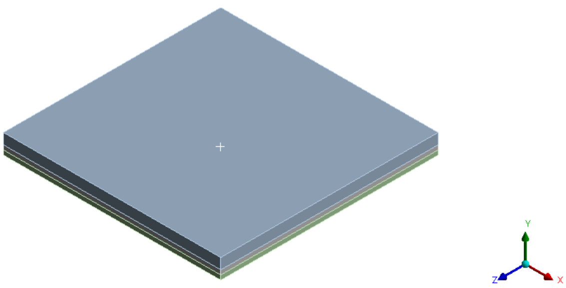
$$h = -15 \times (12 - t) \tag{16}$$

## ANALYTICAL ANALYSIS

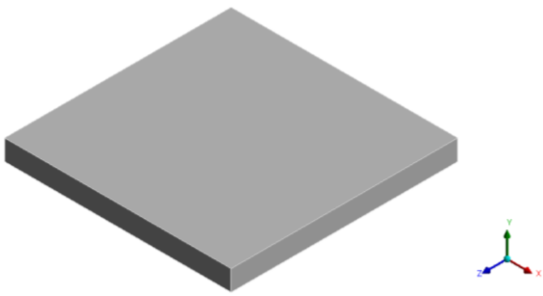
Building roof slabs are thermally analyzed using ANSYS software and the building roof slab is designed using the design modular ANSYS work bench 2022 R2 student edition. The design modular ANSYS work bench model created for the current numerical simulation is shown in Figures. 14-16. The current study makes use of ANSYS' transient thermal analysis module. The model has been meshing, and the thermal analysis is using the boundary conditions. To estimate the inside surface at the bottom surface of the roof, the top surface of the roof is kept at an experimental input value on an hourly basis. Unsteady state conditions are used to start the simulations.

### TRANSIENT THERMAL ANALYSIS ON A CONCRETE SLAB

The geometric model of the concrete slab is modeled in the ANSYS Workbench 2022 R2 student version using design modeler. The geometry of the four models are shown in the below Figures 14–16.



**I**



**II**

**Figure 14.** I and II are Isometric View of the slab PCM 1, PCM 2 & Concrete.

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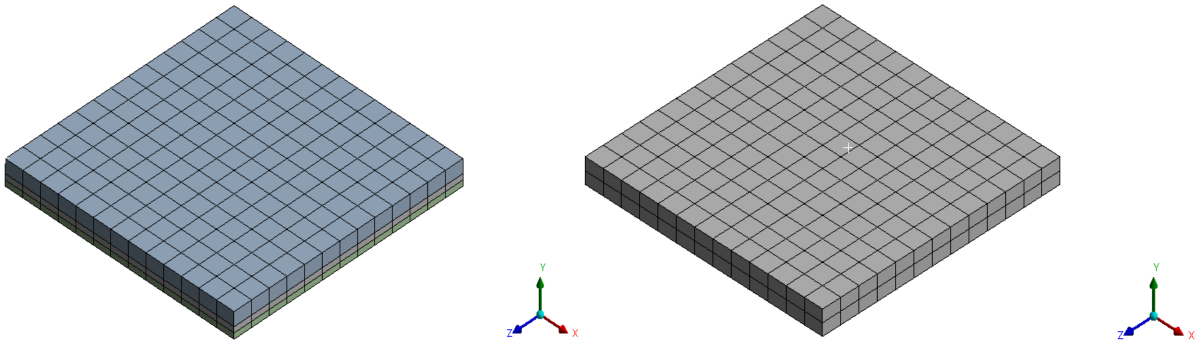
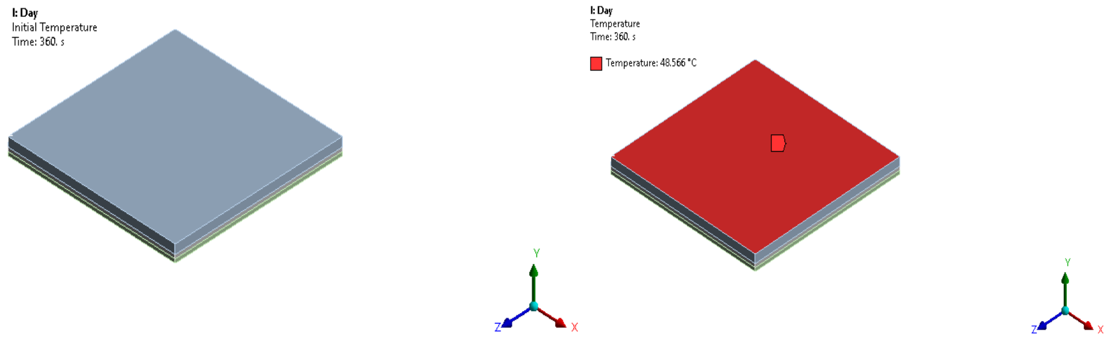



**III** **IV**

**Figure 15.** III and IV are Meshing of PCM 1, PCM 2 & Concrete.




**V** **VI**

**Figure 16.** V and VI Initial temperature of concrete slab.

The process of converting geometry entities into finite elements is called meshing. Here 8 node quadrilateral element is used. Element sized used in this analysis is 100 mm.

In this step the body temperature of the concrete slab is assigned. Temperature as a load for the concrete slab is assigned on the top surface for 3600 seconds which are shown in the below fig 16.

Figures 17–18 Graphs are drawn between room temperature Practical and FEM Analysis for PCM (Green material II) and RCC for the month of march 2021 at peak hour. The percentage of error between them 5%.

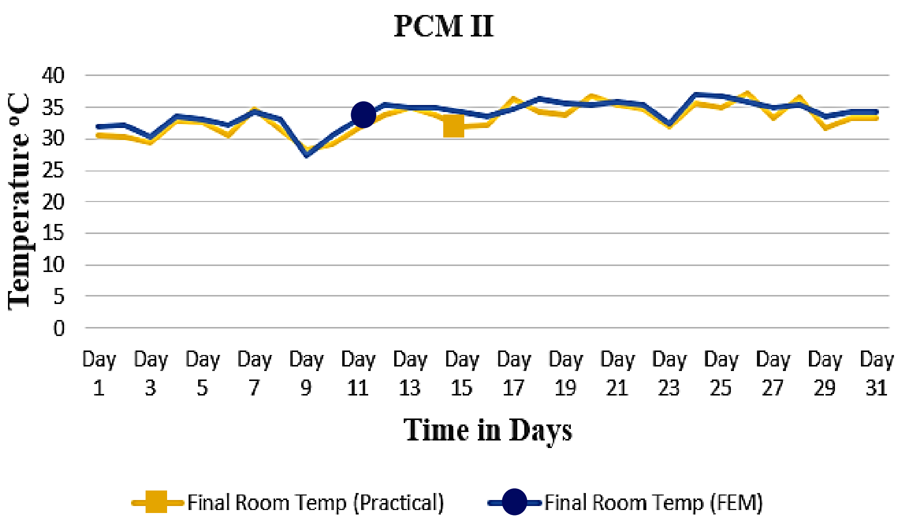



**Figure 17.** Temp against time in days during the top of the march 2021 month.

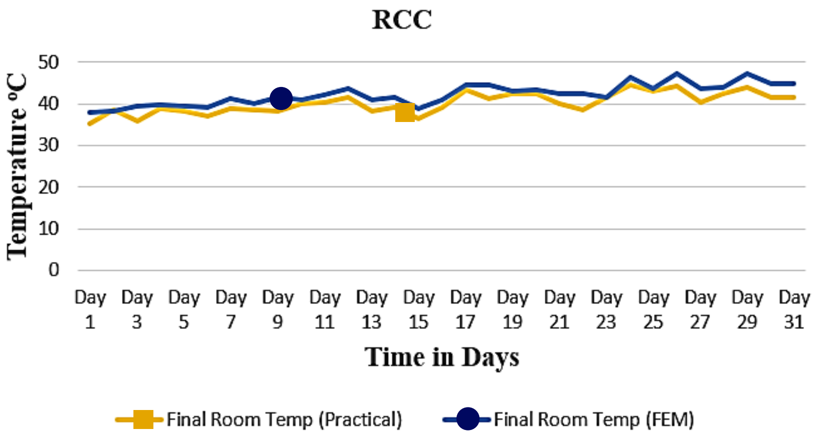



**Figure 18.** Temp against time in days during the top of the march 2021 month.

## CONCLUSION

From March 1 to March 31, 2021, which is mostly the summer season at the test area, experimental experiments are carried out. Building cooling is necessary during these times in the tested region (Anantapur-India). In the tests, the temperatures are continuously and continuously monitored for 24 hours a day in the four identical rooms under the same environmental circumstances. Following is a discussion of temperature fluctuations at several areas in both buildings:

- The time lag for PCM (Green material II) is less when compared to other slabs and is suggestible for better thermal performance inside the room.
- The decrement factor for PCM (Green material II) is less when compared to other slabs and is suggestible for better thermal performance inside the room.
- The inside room air temperature for PCM (Green material II) is less when compared to other slabs and is suggestible for better thermal performance inside the room.
- The Ceiling temperature for PCM (Green material II) is less when compared to other slabs and is suggestible for better thermal performance inside the room.

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