PHASE CHANGE MATERIAL AS A THERMAL ENERGY STORAGE MATERIAL FOR COOLING OF BUILDING

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ABSTRACT

As the demand for refrigeration and Air conditioning has been increased during the last decade, the cool storage systems can be used to the economic advantage over conventional cooling plants. Cool storage system using phase change materials can be used for peak load shifting if they are installed in the building. In the case of sensible heat storage system, energy is stored or extracted by heating or cooling a liquid or a solid, which does not change its phase during the process. A variety of substances like water, heat transfer oils and certain inorganic molten salts, and solids like rocks, pebbles, and refractory are used. The choice of the substances used largely depends upon the temperature level of the application. Phase change material (PCM) are one of the latent heat materials having low temperature range and high energy density of melting – solidification compared to the sensible heat storage. The tests on transient heat transmissions across different roof structures were conducted. It was found that when installing PCM in the withering course (WC-mixture of broken bricks and lime mortar) region nearly uniform roof bottom surface temperature was maintained.

Keywords: *Phase Change Material (PCM), Energy storage, Latent heat storage (LHS), Withering Course (WC), Natural Cooling, Building roof, heat transmission.*

1. INTRODUCTION

As a demand for air conditioning increased greatly during the last decade, large demands of electric power and limited reserves of fossil fuels have led to a surge of interest with efficient energy application. Electrical energy consumption varies significantly during the day and night according to the demand by the industrial, commercial and residential activities. In hot and cold climate countries, the major part of the load variation is due to the air conditioning and space heating respectively. This variation leads to a differential pricing system for peak and off peak periods of energy use. Recent discussions on topics like global warming and heat waves have brought attention once again to energy efficient cooling systems utilizing renewable energy sources. Cooling demand has already been increasing due to the evolving comfort expectations and technological development around the world. Climate change has brought additional challenges for cooling systems designers. Significant economic benefit can be achieved by thermal energy storage for heating and cooling in residential and commercial buildings. Buildings that will have large mass will react slowly to changes in heating and cooling demands.

Efficient and economical technology that can be used to store large amounts of heat or cold in a definite volume is the subject of research for a long time. Thermal storage plays an important role in building energy conservation, which is greatly assisted by the incorporation of latent heat storage in building products. Devices which store heat during peak power operation and release the same during reduced power operation. Phase change material is one of the thermal storage devices.

LHS in a phase change material (PCM) is very attractive because of its high storage density with small temperature swing. It has been demonstrated that for the development of a latent heat storage system in a building fabric, the choice of PCM plays an important role in addition to heat transfer mechanism in the PCM. Thermal energy storage in the walls, ceiling and floor of the buildings may be enhanced by encapsulating or embedding suitable PCMs within these surfaces. They can either capture solar energy directly or thermal energy through natural convection. Increasing the thermal storage capacity of building can increase human comfort by decreasing the frequency of internal air temperature swings so that indoor air temperature is closer to the desired temperature for a longer period of time. This system provides a valuable solution for correcting the difference between the supply and demand of energy. Latent heat storage is a new area of study and it received more attention during early 1970s and 1980s.

Many phase change materials has been studied and tested for different practical uses by many scientists. This paper attempts to analyse the information about application of PCM in the building roofs for residential and commercial establishments.

2. PCM CLASSIFICATION AND PROPERTIES

In 1983, Abhat [1] gave the general classification of energy storage material in Fig.1 and also by Lane [2, 3], Dinser and Rosen [4]. These papers gave the full detail like classification and characteristics of PCM. B.Zalba [5] listed the properties of different PCM's (Organic, Inorganic, Fatty acids) like density, specific heat, thermal conductivity and melting temperature.

Some of the important properties required for PCM are

- High latent heat of fusion per unit mass, so that a lesser amount of material stores a given amount of energy.
- High specific heat that provides additional sensible heat storage effect and also avoid sub cooling.
- High thermal conductivity so that the temperature gradient required for charging the storage material is small
- High density, so that a smaller container volume holds the material
- A melting point in the desired operating temperature range.
- The phase change material should be non-poisonous, non-flammable and non-explosive.
- No chemical decomposition, so that the (LHTS) system life is assured.
- No corrosiveness to construction material
- PCM should exhibit little or no super cooling during freezing.

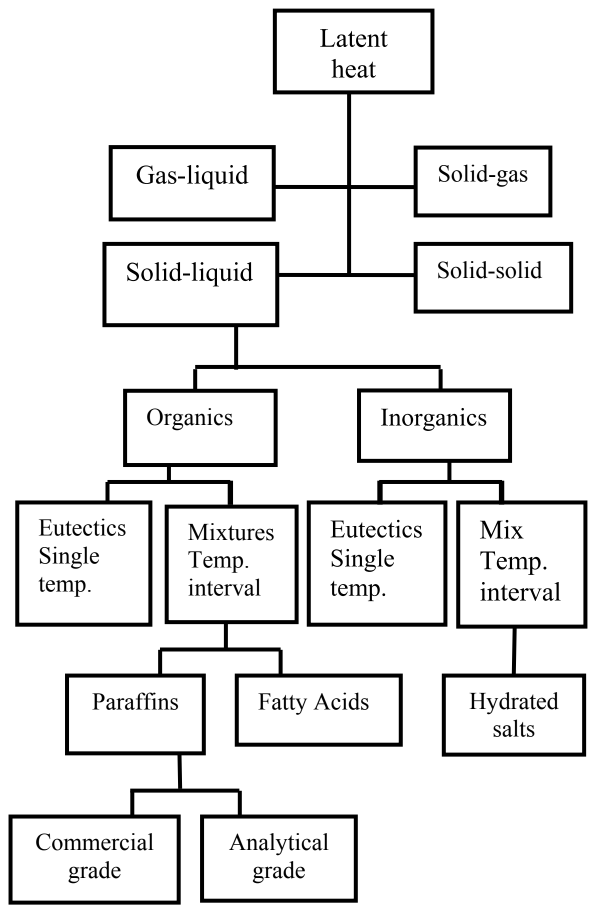


Figure 1. Classification of PCM

PCMs have not always resolidified properly, because some PCMs get separated and stratify when in their liquid state. When temperature dropped, they did not completely solidify, reducing their capacity to store latent heat. These problems are overcome by packaging PCM in containers and by adding thickening agents.

To solve some of the problems inherent in inorganic PCMs, an interest has turned towards a new class of materials: low volatility, anhydrous organic substances such as paraffin's, fatty acids and polyethylene glycol. Those materials were more costly than common salt hydrates and they have somewhat lower heat storage capacity per unit volume. It has now been realized that some of these materials have good physical and chemical stability, good thermal behavior and adjustable transition zone. When salt hydrates are used as PCM they have a tendency to super cool and do not melt congruently so that segregation results. Even though advances were made, some hurdles remained towards the development of reliable and practical storage systems utilizing salt hydrates and similar inorganic substances.

Hydrated salts are attractive materials for use in thermal energy storage due to high volumetric storage density, relatively high thermal conductivity and moderate costs compared to paraffin waxes. Glauber salt ($Na_2SO_4 . H_2O$) which contains 44% Na_2SO_4 and 56%H_2O has been studied in 1952 [6,2], and it has melting temperature of 32.4ºC, latent heat of 254Kj/Kg. The selection of such material as PCM for a specific application should be based on thermodynamic properties, kinetic properties and chemical properties. For low temperature applications ranging from 0°C to 99°C, Salt Hydrates would be the best option owing to their availability in a less temperature range with a reasonable specific heat capacity of 133.4(cal/deg.mol), thermal conductivity of 0.987 W/m-K, density of 1552 kg/m^3 in the solid phases respectively and phase transfer temperature ranging from 35°C - 39°C.

3. DEVELOPMENT OF PCM FOR COOLING OF BUILDINGS

The PCM can be used as natural heat and cold sources or manmade heat or cold sources. In any case, storage of heat or cold is necessary to match availability and demand with respect to time. There are three different ways to use PCMs for heating and cooling of buildings exist:

-PCMs in building walls;
-PCMs in building components other than walls i.e in ceilings and floors;
-PCMs in separate heat or cold stores.

The first two are passive systems, where the heat or cold stored is automatically released when indoor or outdoor temperatures rise or fall beyond the melting point. The third one is active system, where the stored heat or cold is contained thermally separated from the building by insulation. Therefore, the heat or cold is used only on demand and not automatically. In building applications, only PCMs that have a phase transition close to human comfort temperature (20–28ºC) can be used. Some Commercial PCMs have been also developed for building application.

Hawes and Feldman [7] have considered the means of PCM incorporation into the building by direct incorporation, immersion and encapsulation. Arkar and Medved [8] designed and tested a latent heat storage system (LHS) used to provide ventilation of a building. Stritih and Novak [9] designed an 'experimental wall' which contained black paraffin wax as the PCM heat storage agent. The stored heat was used for heating and ventilation of a house. Peippo et al. [10] considered a PCM impregnated plasterboard as a storage component in a lightweight passive 120m^2 solar house with good insulation and a large area of south facing glazing in Madison, Wisconsin .The house could save up to 3GJ in a year or 15% of the annual energy cost. Stetiu and Feustel [11] used a thermal building simulation program based on the finite difference approach to numerically evaluate the LHS performance of PCM wallboard in a building environment. Feustel and Stetiu also investigated using double PCM-wallboard to further increase the storage capacity of a building so that the room temperatures could be kept closer to the upper comfort limits without using mechanical cooling. Neeper [12] has examined the thermal dynamics of a gypsum wallboard impregnated by fatty acids and paraffin waxes as PCMs that are subjected to the diurnal variation of room temperature but are not directly illuminated by the sun. Salyer and Sircar [13] defined a suitable low-cost linear alkyl hydrocarbon PCM from petroleum refining and developed methods of containing the PCM in plasterboard to eliminate leakage and problems of expansion in melting and freezing. Athienitis et al. [14] conducted an extensive experimental and one dimensional nonlinear numerical simulation study in a full scale outdoor test room with PCM gypsum board as inside wall lining. Lee et al. [15] have studied and presented the results of macro-scale tests that compare the thermal storage performance of ordinary concrete blocks with those that have been impregnated with two types of PCMs, BS and commercial paraffin. Hawes et al. [16] presented the thermal performance of PCM's (BS, dodecanol, paraffin, and tetradecanol) in different types of concrete blocks. The presentation has covered the effects of concrete alkalinity, temperature, immersion time and PCM dilution on PCM absorption during the impregnation process. Hadjieva et al. [17] have applied the same impregnation technique for concrete but with sodium thiosulphate penta hydrate (Na2S2O3.5H2O) as a PCM. Mehling et al. [18] were found that PCMs can be combined with wood–lightweight concrete and that the mechanical properties do not seem to change significantly. It forwards a new kind of under-.floor electric heating system with shape-stabilized PCM plates. Different from conventional PCM, shape-stabilized PCM can keep the shape unchanged during phase change process. Therefore, the PCM leakage problem can be avoided. This system can charge heat by using cheap night time electricity and discharge the heat stored at daytime.

A major development in this area is to develop a PCM which will maintain good heat storage during the day and heat loss to the environment during night time.

4. PROBLEM FORMULATION

4.1 Roof types and study area

Three roof structures are taken for studies are as follows:

Roof -1(RCC): simple RCC roof (150mm thick);

Roof -2 (WC): RCC roof (150mm thick) covered with withering course -WC (75 mm thick);

Roof -3(PCM): RCC roof (150mm thick) covered with WC (75mm thick) having PCM in the WC region.

4.2 Assumptions made

To study the system the following assumptions are made:

i. The temperature variation is two dimensional (across width and depth directions only);

ii. The ambient temperature T_{amb} and solar heat flux q_s are the functions of time over the day;

iii. The material properties are constant;

iv. Inside and outside heat transfer coefficients are constant;

v. Radiation heat exchange within the room is neglected;

Due to similar symmetry of all these structures, width of all roofs were taken equally (150mm) for the investigation. Boundary conditions were same for all types of roof.

4.3 Boundary conditions

For right and Left $\frac{\partial T}{\partial X} = 0$

Bottom surface Convection, hi =10w/m^{2}k,

T =25°c

Top surface Convection, ho = 10w/m^{2}k,

T =hourly values

Solar radiation flux, q = hourly values

5. MATERIALS AND METHODS

The temperature distribution inside the roof as analyzed by using the Finite element analysis software ANSYS 10. The parameters required for the analyses are given below.

Table 1. Material property Data

Material	Density (Kg/m^3)	Thermal Conductivity (W/mK)	Specific Heat (J/Kg K)
Concrete	2300	1.279	1130
Withering course	1300	0.25	800
Phase Change Material (PCM)	941*	0.172*	2.35*
	Latent heat		172

*- indicates for both solid and liquid state

Solar insulation and weather data of Coimbatore city, Tamilnadu, India during June was used. $T_{sol-air}$ was found out by using the formula

$T_{sol} = T_{amb} + (\alpha q_s / h_0)$.

The graph between the Time vs. T_{amb} and Time vs. $T_{sol-air}$ was plotted as shown in the Fig.3.

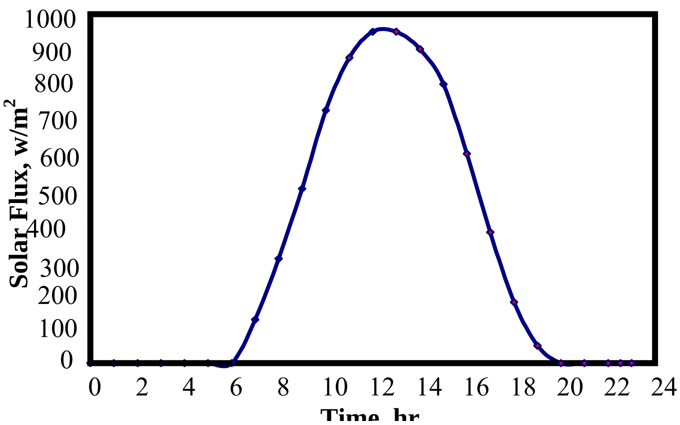


Figure 2. Solar Radiation Data for Coimbatore during June 2006

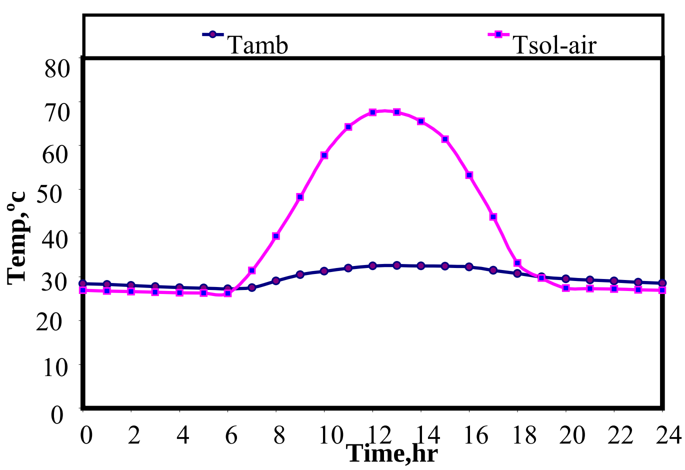


Figure.3. Weather data for Coimbatore during June 2006

6. TYPES OF ROOF TAKEN FOR STUDY

Roof structures were modeled and solved using thermal module of Ansys finite element analysis software. Three types of roof were considered for the case study as shown in the Fig.4. Grid refinement was carried out and the numbers of elements used were 5000. The roof was maintained at uniform temperature of 25ºc to start the solution for the transient thermal analysis. The effect of this initial condition on the end results are avoided by repeating the solution for several days till the temperature distributions at the end of two consecutive days are equal. About 5days x 24 hours was found to be sufficient for attaining the solution. The 5th day results are presented and discussed.

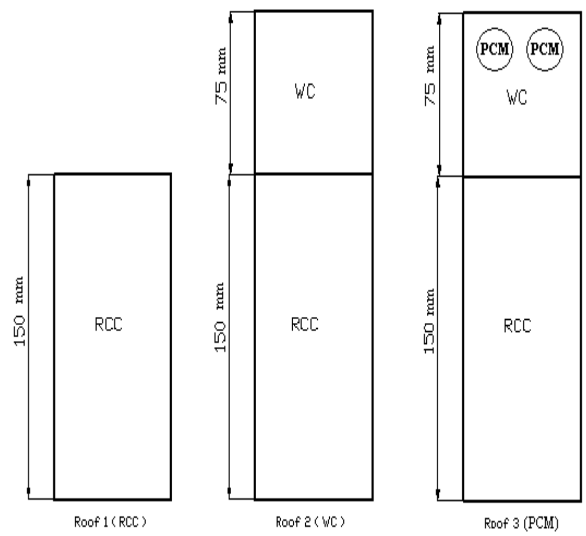


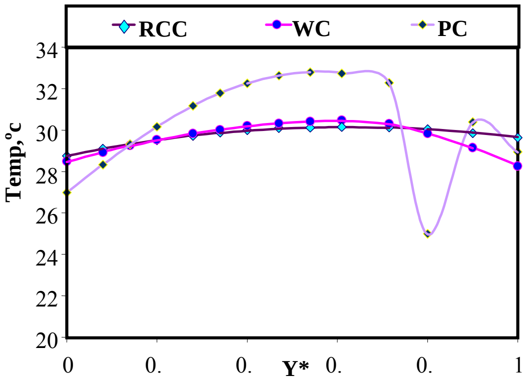
Figure.4. Roof Structures

7. RESULTS AND DISCUSSION

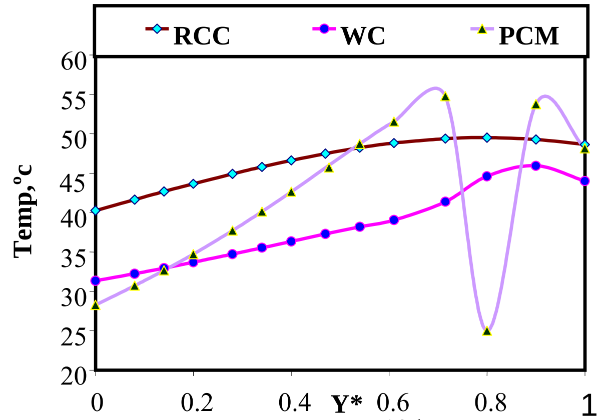
The solar radiation data for Coimbatore during June 2006 was recorded as shown in the fig 2. The thickness of all the three roof structures are different, so the distance is normalized (Y*=Y/Ymax) with Y=0, Y*=0 referring to the bottom of the roof and Y=Ymax and Y*=1.0 referring the top surface of the roof.

7.1 Temperature distribution across the roof structure

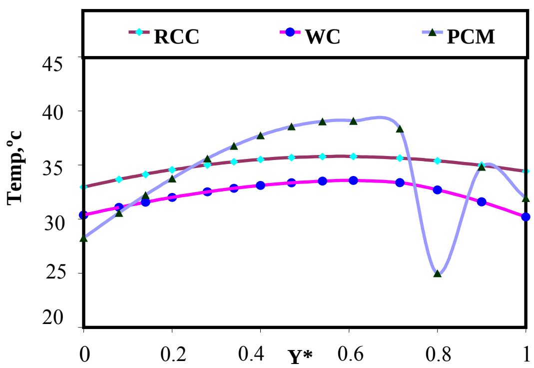
At τ =0 hr to τ =6 hr, there is no solar radiation on the building surface. But the heat accumulated in the middle structure during the previous day, travels on both the sides of the roof. The temperatures at the top and bottom surfaces are lower compared to the temperature inside the roof. The average temperature for the concrete structure is the highest among all the other types of roofs as the thermal conductivity of RCC is more compared to the WC and PCM. As the thermal conductivity of RCC is higher, more heat.



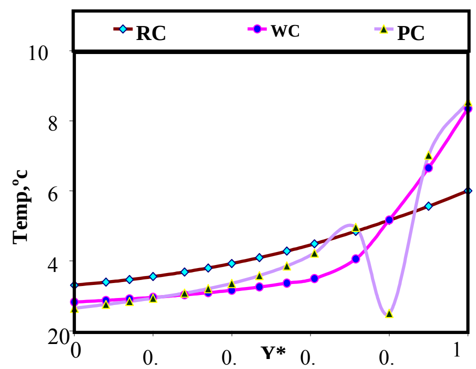
τ = 0 hr



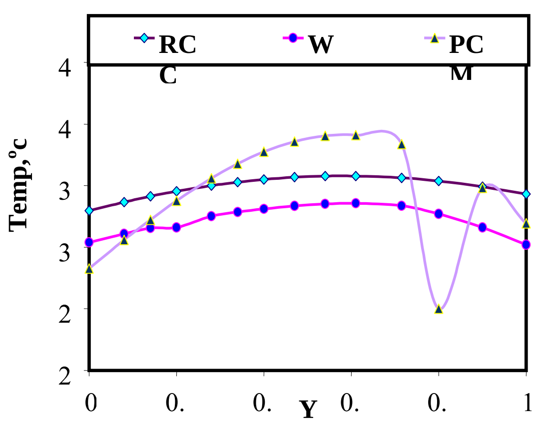
τ = 18 hr



τ = 6 hr



τ = 24 hr



τ = 12 hr

will be stored during the previous day. The thermal conductivity of Roof 3 is lowest compared to Roof 2 and Roof 1

The curve for Roof 3 falls below the other curves because PCM absorbs maximum heat energy passing through the roof. It brings down the temperature to the room temperature at the place where it is located.

At τ =6 hr to τ =12 hr, as the solar radiation falling on the surface increases, the heat transfer characteristics varying from the previous time period. As the thermal conductivity of the RCC is highest, whatever the heat enters all the heat will be transferred to the bottom so the curve is linear and average. The curve for the Roof 2 is also similar to the Roof 1 curve but slightly falls below the Roof 1 curve at the bottom and peak value at the top. The curve for the PCM reaches the least value at the bottom and it reaches the peak value in the top layer.

At τ =12 hr to τ =18 hr, the solar radiation falling on the roof decreases but the heat that has already entered travels inside the roof. The mid plane temperature values are higher than the τ =12 hr. As the heat flux during this τ =18 hr is very small value, so the convection at the roof top dominates during this period. Compared to the Roof 1, Roof 3 has reduced the temperature at the bottom of the roof by 12º.

During τ =18 hr to τ =24 hr, there is no solar radiation entering the roof. So the temperature at the top and bottom of the roof is nearly at the same temperature. For the Roof 3, temperature reaches peak value at the middle and in the WC region where PCM is located temperature falls suddenly to room temperature as the PCM absorbs all the heat passing through the roof. And it reaches almost least value at the bottom as the PCM installed region acts as thermal energy storage.

7.2 Variation of roof top surface temperature

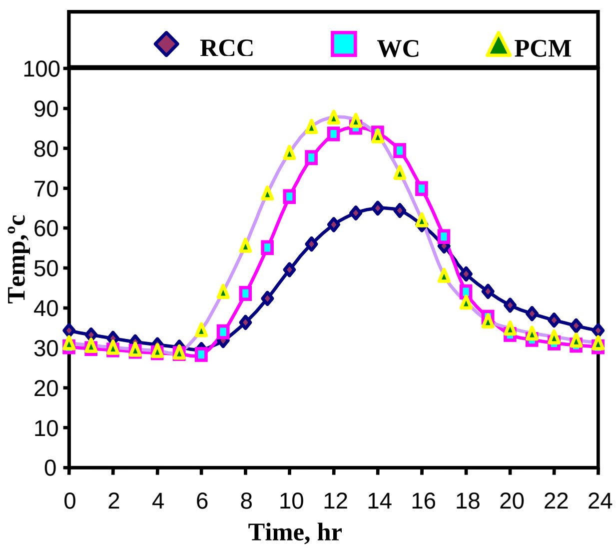


Figure.5 Roof top surface temperature

Fig.5 shows the variation of top surface temperature along with T_{amb} and $T_{sol-air.}$ During τ =0hr to τ =6hr and τ =18hr to τ =24hr the top surface temperature reaches the low values. The temperature for the WC roof attains the lowest value and WC with PCM attains the highest value, because even though in the absence of solar radiation the PCM has stored heat energy during the previous day releases the energy to the top surface. During τ =6hr to τ =18hr the solar radiation initially increases and drops later, the top surface temperature for all the roofs increases initially and drops later. The lease value is observed for the RCC structure and highest value for the WC with PCM structure. This is because WC and WC with PCM structure offers more resistance for the heat flow than the RCC structure makes the top surface temperature to go high for these two structures.

7.3 Variation of roof bottom surface temperature

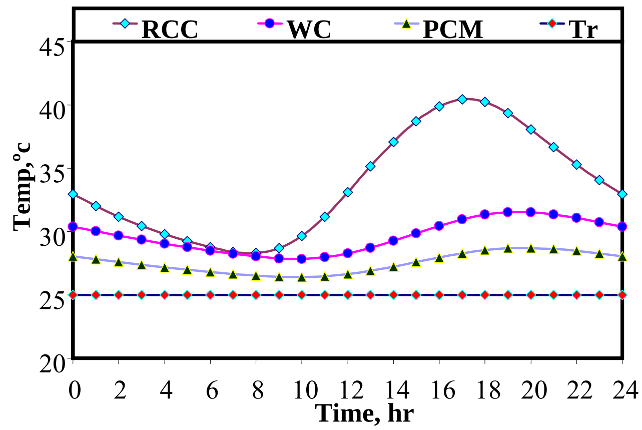


Figure. 6 Roof bottom surface temperature

The bottom surface temperature for three different roof structures are plotted for different time period during the day along with the room temperature (Tr). The net heat entering in to the room is mainly determined by the bottom surface temperature. In the case of RCC roof, it has good thermal conductivity, so the heat travels freely into the room and the room temperature is remarkably high value. The RCC with WC structure offers some resistance so the bottom temperature drops significantly. For the WC with PCM structure, as the thermal conductivity of PCM is very low it offers high resistance for heat flow, so the bottom temperature is nearly maintained constant.

7.4 Variation at the middle of the structure

In the RCC roof the middle surface at τ =0 hr to τ =6 hr, there is no solar radiation on the building surface. But the heat accumulated in the middle structure travels on both the sides of the roof. The temperatures at the top and bottom surfaces are lower compared to the temperature inside the roof. The average temperature for the concrete structure is the highest among all the other types of roofs as the thermal conductivity of RCC is more compared to the WC, WC with PCM. As the thermal conductivity of RCC is higher, more heat will be stored during the previous day. The thermal conductivity of WC with PCM is lowest compared to WC and RCC. The curve for WC with PCM falls below the other curves because PCM absorbs maximum heat energy passing through the roof. It brings down the temperature to the room temperature, where the PCM is locate face temperature goes on decreasing up to τ =7hr. As the solar radiation increases later the temperature starts increasing up to τ =0 hr to τ =6 hr, there is no solar radiation on the building surface. But the heat accumulated in the middle structure travels on both the sides of the roof. The temperatures at the top and bottom surfaces are lower compared to the temperature inside the roof. The average temperature for the concrete structure is the highest among all the other types of roofs as the thermal conductivity of RCC is more compared to the WC, WC with PCM. As the thermal conductivity of RCC is higher, more heat will be stored during the previous day. The thermal conductivity of WC with PCM is lowest compared to WC and RCC. The curve for WC with PCM falls below the other curves because PCM absorbs maximum heat energy passing through the roof.

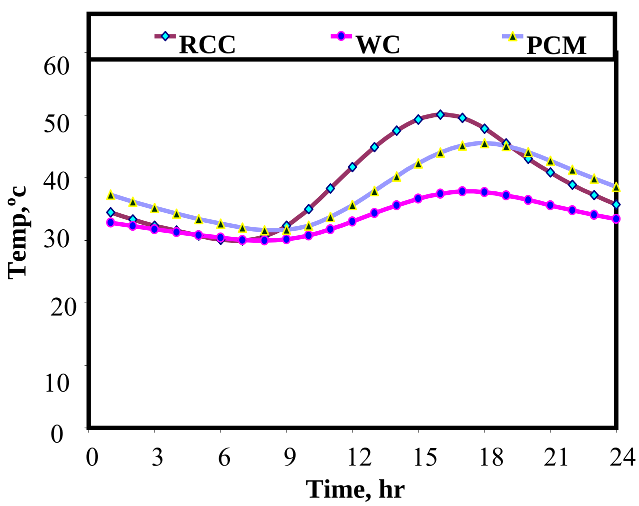


Figure.7 Middle surface temperature

It brings down the temperature to the room temperature, where the PCM is located. rts increasing up to τ =16hr and then drops later. For WC and PCM roof the surface temperature goes on decreasing up to τ =9hr as these roofs offer some resistance to heat flow compared to the RCC roof. Up to τ =18hr, both the curves are linearly increases and then drops later.

7.5 Heat flux entering into the room

From the Fig.8 it clearly states that PCM installed roof is better than the WC roof and RCC roof. If the roof is installed with PCM it can reduce the heat entering the room about more than two-third than the RCC laid roof.

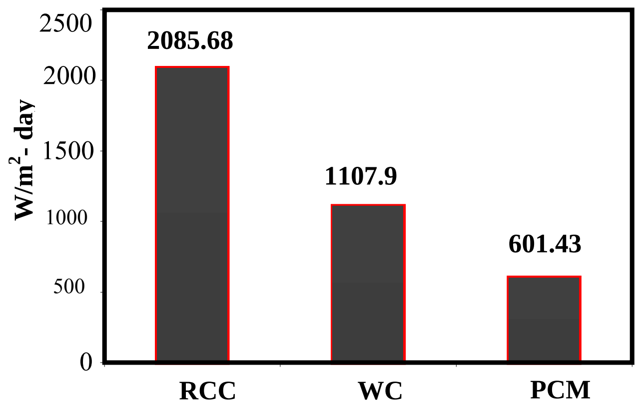


Figure.8 – Heat Flux entering the room

When compared with the RCC, the WC and PCM roof reduces the heat transfer by 46.88% and 71.16%.As compared to WC roof with PCM roof, reduction in net heat transfer was found to be 45.71%.The reduction in heat transfer is directly proportional to the corresponding reduction in the electrical energy consumption for to maintain the room at 25°c.

8. CONCLUSIONS

Natural Cooling of building with phase change material was studied. The heat entering in to the room was maximum with RCC laid roof, because the thermal conductivity of RCC is high value. So almost all the heat entering the roof was transferred to the room. When WC was laid along with RCC and WC with PCM laid roof the heat entering the room was reduced by 46.88% and 71.16%.As the PCM is having low thermal conductivity, it offers the resistance for the heat flow and heat transfer was reduced by 45.71 compared to the RCC with WC roof. With various combinations of PCM, the test can be repeated to find the best and effective material for cooling application. The effects of thermo physical properties of PCM, installation methodology, location of PCM are the scope for future work.

9. NOMENCLATURE

T_{sol} = Sol temperature
T_{amb} = Ambient temperature

α = absorption coefficient
q_s = heat flux in w/m^2
h_0 = room outside heat transfer coefficient
h_i = room inside heat transfer coefficient
A_r = cross sectional area of the room in m^2
T_r = room temperature in degree

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REFERENCES

[1]. Abhat.A, “Low temperature latent heat thermal energy storage, Heat storage materials”, solar energy, 1983; 30,pp. 313-32.

[2]. G.A.Lane, “Solar heat storage: Latent heat Material”, vol II, Technology, CRS Press, Boca Raton, FL, 1986.

[3]. G.A.Lane, “Solar heat storage: Latent heat Material”,vol I, Background and scientific principles, CRC press, Florida 1983.

[4]. I.Dincer, M.A.Rosen, “Thermal energy storage, systems and applications”, John Wiley and sons, chickaester (England) 2002.

[5]. Belen zalba, Jose M.Marin, Lusia Feabeza, Harald Mehling, “Review on thermal energy storage with phase change materials, heat transfer analysis and application”, Applied thermal engg 23(2003), pp.251-283.

[6]. Biswas DR.,“Thermal energy storage using sodium sulphate decahydrate and water”, solar energy,1977, 19,pp.99-100

[7]. Hawes DW, Feldman D, “Absorption of phase change materials in concrete”, Solar Energy Material and Solar Cells, 1992, Vol.27, pp.91–101.

[8]. Arkar C, Medved S, “Enhanced solar assisted building ventilation system using sphere encapsulated PCM thermal heat storage”. IEA, ECES IA Annex 17, advanced thermal energy storage techniques—feasibility studies and demonstration projects 2nd workshop; 3–5 April 2002, Ljubljana, Slovenia.

[9]. Stritih U, Novak P, “Thermal storage of solar energy in the wall for building ventilation” Second workshop: IEA, ECESIA Annex 17, Advanced thermal energy storage techniques—feasibility studies and demonstration projects, Ljubljana, Slovenia. 3–5, April 2002.

[10]. Peippo K, Kauranen P, Lund PD, “A Multi component PCM wall optimized for passive solar heating”, Energy Building, 1991, Vol. 17, pp.259–270.

[11]. Feustel HE, Stetiu C, “Thermal performance of phase change wallboard for residential cooling application” Lawrence Berkeley National laboratory, Report LBL-38320,1997.

[12]. Neeper D, “Thermal dynamics of wall board with latent heat storage”, Sol Energy, 2000, 68, pp.393– 403.

[13]. Salyer IO, Sircar AK, “Phase change materials for heating and cooling of residential buildings and other applications” In: Proceedings of 25th intersociety energy conversion engineering conference.1990, pp.236–43.

[14]. Athienitis AK, Liu C, Hawes D, Banu D, Feldman D, “ Investigation of the thermal performance of a passive solar test-room with wall latent heat storage” Building and Environment,1997, 32,pp.405–10.

[15]. Lee T, Hawes DW, Banu D, Feldman D, “Control aspects of latent heat storage and recovery in concrete”, Sol Energy Material and Solar Cells, 2000, 62,pp.217–37.

[16]. Hawes DW, Banu D, Feldman D, “Latent heat storage in concrete II”, Solar Energy Materials, 1990, 21, pp.61–80.

[17]. Hadjieva M, Stoykov R, Filipova T, ”Composite salt-hydrate concrete system for building energy storage”, Renewable Energy, 2000, 19,pp. 11–15.

[18]. Mehling R, Krippner A, Hauer, “Research project on PCM in wood–light weight-concrete”, In Proceedings of the second workshop of IEA ECES IA Annex 17,Ljubljana, Slovenia, 2002.