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Incorporation of phase change material for passive cooling in building roof

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ABSTRACT

Thermal storage plays a major role in a wide variety of industrial, commercial and residential application and there was some mismatch between the supply and demand. In the present work, a detailed study on thermal performance of PCM based thermal storage for energy conservation in the building is analyzed and discussed. It considers the cooling of a building in the summer season using PCM. The PCM melts by absorbing solar radiation in the daytime, and it's solidified by releasing heat in the night time. An experimental arrangement consisting of two identical test rooms has been constructed to study the effect of PCM panel on the roof of the building. One roof is built without PCM and compared to roof with PCM panel. The temperature of the room with PCM is found to be decreasing from 36°C to 30°C during daytime whereas it increases from 28°Cto 32°C during night time. However without PCM on the roof, the room temperature is observed to the maximum of 36°Cduring daytime, and it's in the range between 28°C to 30°C during nighttime.

KEY WORDS: Latent heat thermal energy storage, Space heating and cooling, Building energy conservation

1. INTRODUCTION

The current scenario of the global energy crisis is such that the available energy resources are estimated to last no longer than 300 years, all conventional resources put together. In china, building energy consumption doubled from 1998 to 2009. The share of total energy consumption in building has been increased from 20%to40% (Kong, 2012). The increasing building energy consumption lead to such problems as supply difficulties overuse of energy resources, climate change, environmental pollution (Zhang, 2013). Phase change materials (PCM) that can absorb, store and release heat and cold according to the surrounding environmental conditions provide an alternative for building materials (Smith, 2010). Therefore, it was very effective in shifting the heating and cooling load to off -peak electricity periods. As a result of high thermal mass, PCM walls are capable of minimizing the effect of large fluctuations in ambient temperature on the inside temperature of a buildings. Various materials like PCM enhance buildings, materials that include PCM- gypsum boards, PCM-integrated concretes and PCM impregnated concretes and PCM enhanced fiber insulation are already limited use in many countries.

Castell (2010) conducted an experimental setup to test phase change materials with an alveolar brick for Mediterranean construction in real test conditions. Several cubicles constructed and their thermal performance throughout the time was measured. For each building material, RT-27and SP-25 A8PCM is added in one cubicle. The experiments can show that the PCM can reduce the peak temperature up to 18°C and smooth out the daily fluctuations. The thermal effectiveness of the building roof with PCM had been studied by Alavadhi (2011). The considered model consists of a concrete slab with vertical holes filled with PCM. The thermal effectiveness of the proposed roof-PCM system has determined by comparing the heat flux at the indoor surface and roof without PCM during typical working hours. It was found that neicosane PCM showed the best performance among the examined PCMs. The results also indicate that the heat flux at the indoor surface of the roof can be reduced up to 39%for a particular type of PCM. Latent heat thermal energy storage was integrated into cooling system in buildings to cool the rooms during peak load while charging the storage system during off peak period (Agyenim, 2010). PCM can also be integrated into a building wall to act like a heat reservoir to provide thermal comfort by reducing the cooling/heating loads. There is a significant increase in comfort condition even in the absence of air conditions (Fang, 2006). A PCM cold storage unit incorporated in air conditioning systems in buildings has been built and studied. The PCM is solidified during the night and use to cool the interior of the building during the hottest hour of the day. This concept is known as free cooling (Butala, 2009). Berroug (2011) analyzed the thermal performance of a north wall made with hydrated salt phase change material as a storage medium in east- west oriented greenhouse. A numerical study has been developed to investigate the impact of the PCM on greenhouse temperature. The results show that with an equivalent to 32.4kg of PCM per square meter of greenhouse area, the temperature of the inside air was found to be 6°C more at night in winter period with very less fluctuations. Edwin Rodriguez (2012) investigated the usage of PCMs in the buildings and also discussed various applications. They dealt with the way in which these PCMs can be used along with concrete. They gave out two ways in which the PCM can be incorporated such as active and passive manner. When the PCM is used as a single layer, they are classified as component and if they are mixed with the construction material they are said to be integrated. Pasupathy (2002) investigated the usage of a dual layer of PCM in building roofs. It was found that the rooftop surface temperature is slightly higher than the non-PCM room due to the low thermal conductivity of liquid PCM.

From the literature review, it was found that inorganic salt hydrates have been extensively used as PCM for many applications. This is due to advantageous characters of salt hydrates such as non-poisonous, non-toxic, non-flammable, non-corrosive, chemically stable, relatively high latent heat capacity, but also they have negligible degree of sub cooling during nucleation, no phase separation and only a small volume change in the phase change process. Passive cooling involves designing a building and selecting construction materials in a way that reduces heat absorption and conduction through the walls. The objective of the system is to reduce the energy consumption by minimizing the use of air conditioners. The scope of present work is to study the influence of PCM provided in the roof of a building on the room temperature during daytime.

2. METHODS & MATERIALS

Experimental Investigation: An experimental set up consisting of two identical test rooms (1.2m x 1.2m x2.4m) has constructed to study the effect of having PCM panel on the roof of the building. One room was constructed without PCM panel and another one room with PCM panel which is placed between the bottom concrete slab and rooftop slab. The inner walls except ceiling of the room are insulated by plywood sheet of thickness 5mm on all sides to study the effect of PCM panel on the roof. The PCM panel is made up of stainless steel of (1.15m x 1.15m) and thickness of 3cm which accommodates Inorganic salt hydrates (48% Calcium chloride + 4.3% Sodium chloride + 47% Water+0.4% Potassium chloride).The properties of the salt hydrate used as PCM in the experiment are given below table 1. The mass of the stainless steel is 35 kg, and its capacity is 10 liters. The concrete slab with a thickness of 10cm and the rooftop slab with thickness of 5cm respectively have been made. The roof top slab is a mixture of brick and mortar.

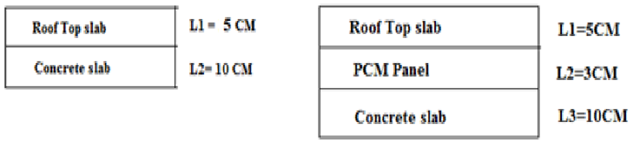


Figure.1. Cross sectional view of the roof (a) without PCM panel (b) with PCM panel

Table.1. Properties of Inorganic salt hydrates

Description	Value
Appearance(color)	Grey
Phase change temperature (°C)	26-28
Density (kg/m^3)	1640
Latent heat (kJ/kg)	188
Thermal conductivity(W/mk) Solid Liquid	 1.09(0-27°C) 0.54(28-60°C)
Specific heat(J/kg K)	1440 (28-60°C)

The temperature variation is recorded for every 30 minutes using RTD (PT Type 100) temperature thermocouple and data's are registered in data acquisition system. Several experiments have been conducted in PCM room for various conditions.

Figure.2. Experimental test room

Project Methodology:

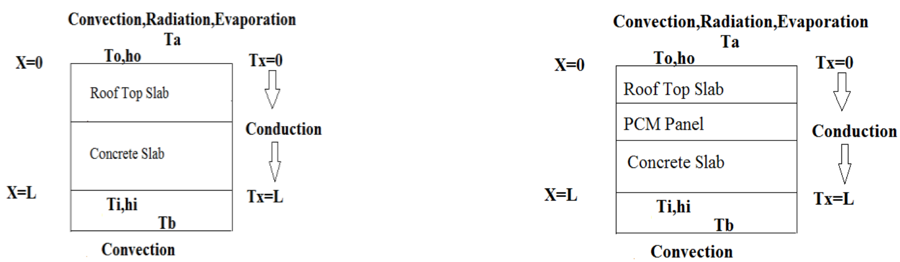


Figure.3. (a) Room without PCM panel on the roof (b) Room with PCM on the roof.

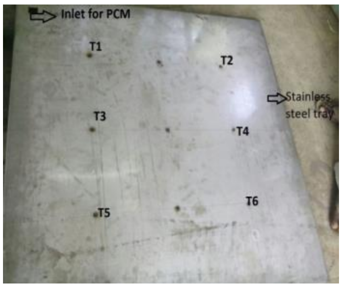


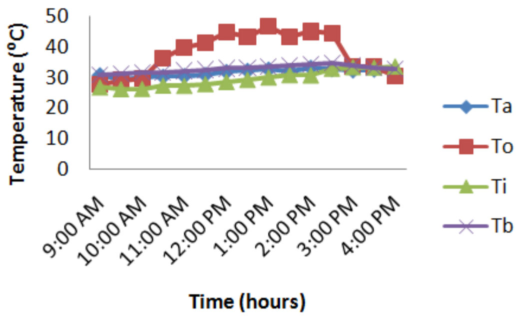
Figure.4.PCM panel

The temperatures associated with the experiments include room temperature, T_b, ambient temperature T_a, roof temperature observed over the rooftop slab, T_o, ceiling temperature, T_i taken over the concrete slab. Six resistance temperature detectors (RTD) are placed at different depths in the PCM panel with perfect sealing as shown in figure 4.

3. RESULTS AND DISCUSSION

Room without PCM on the roof- Daytime: The above graph shows the temperature variation with respect to time during day time. The roof temperature is maintained at 27.5°C in the morning. As the time progresses, it is drastically increased to 45°C during the noon. However the ambient temperature is observed to be fluctuating throughout the duration of experiment. The ceiling temperature and room temperature were initially low (above 26°C). Nevertheless, it was found to be slightly increasing during noon time and again to decrease at the end of day (at 4:00pm).

Room without PCM on the roof- Night time: The above graph shows temperature variation with respect to time during night hours. Initially, all the temperatures i.e., T_a, T_o, T_i & T_b were at a higher temperature of about 30˚C.As time increased, the temperature reduced by a slight variation.



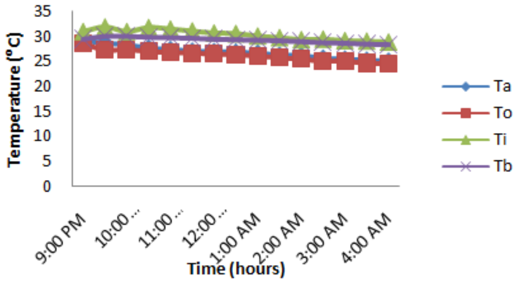


Figure.5. Room without PCM panel on the roof during daytime **Figure.6. Room without PCM panel on the roof during night time**

PCM Temperature- Day time: The thermocouples were fixed in various depth of the PCM panel. It was observed that, the temperatures at all points are closely similar to one another. Initially in the daytime the temperature recorded is 35°C.As time passes, in the noon, the maximum observed temperature reaches to 45°C and again drops to about 30°C at the end of the day.

PCM Temperature- Night time: The above graph shows the temperature variation of PCM panel during night time. The temperatures (T_1 to T_6) have been plotted along y-axis and time along the x- axis. It was observed that initially in the night time temperature was at32°C, as time passes in the night, it gradually decreases to 28°C at 4.00 A.M.

Room with PCM on the roof- Day time: The above graph shows the plot between temperature variations with respect to time. It is observed from the graph that Ti and Tb are continuously maintained at around 29˚C to 30˚C respectively throughout the day. Roof temperature is kept at around 40˚C in the morning and increases to as high as 50˚C in the noon and again drops by evening to around 37.2˚C.Ambient temperature is found to be slightly fluctuating in the range of 28°C to 32.5°C throughout the day. Room temperature is maintained in the range of 26˚C to 30˚C throughout the day.

Room with PCM on the roof-Night time: The above graph shows the plot between temperature variations with respect to time with PCM on the room during the night. It is observed that roof temperature gradually decreases from 28˚C to 26˚C as time elapses. Ambient temperature is found to be very high at around 29°C at 9'o clock and drops as time passes. Then it is maintained at the same temperature throughout the duration of the experiment. Ceiling temperature also decreases, gradually from 31˚C at the start of the test and reaches to 29°C at the end of the trial. Room temperature is initially maintained at 29˚C and it is gradually increased and always maintained at 30°C throughout the duration of the experiment.

Comparison of Room temperature with PCM on the roof and Without PCM on the roof-Day time: It is observed that room temperature with PCM is maintained in the range of 26^{0}Cto 30^{0}C and it is maintained less than 30^{0}C throughout the experiment. Room temperature without PCM is rapidly increased from 30^{0}C to 34^{0}C and it is maintained more than 30^{0}C throughout the experiment.

Comparison of Room temperature with PCM on the roof and without PCM on the roof- Night time: The graph shows a plot between time and temperature for room temperature with and without PCM. It is found that the room temperature with PCM is maintained in the range from 30°C to 31°C throughout the duration of the experiment. While room temperature without PCM on the roof is initially maintained at 30^{o}C and slightly decreased to 28^{o}C at the end of the test.

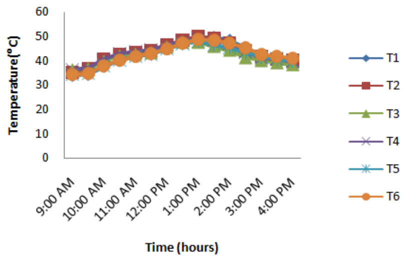


Figure.7.PCM temperature during day time

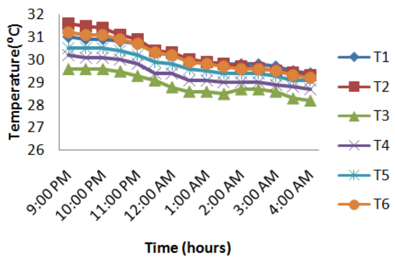


Figure.8.PCM temperature during night time

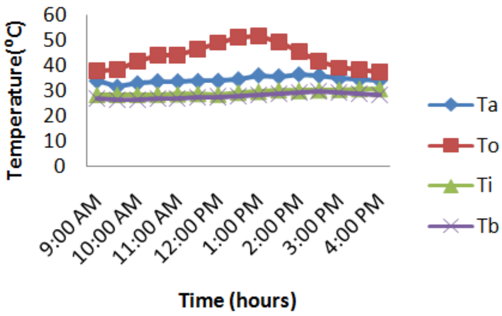


Figure.9. Room with PCM panel on the roof during day time

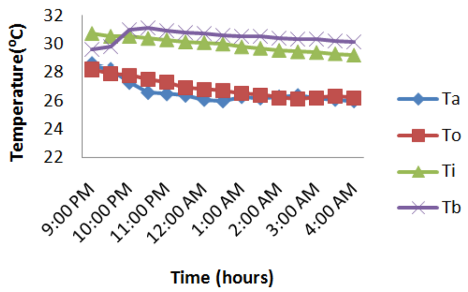


Figure.10. Room withPCM panel on the roof during night time

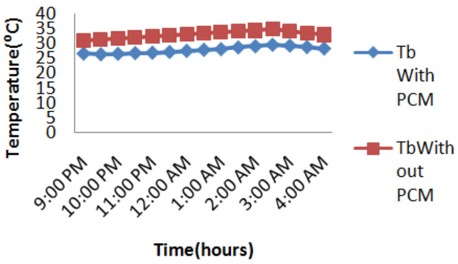


Figure.11.Comparison of room temperature with PCM and without PCM on the roof during day time

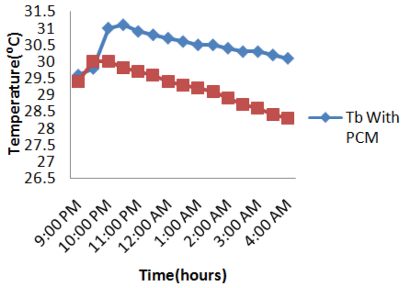


Figure.12. Comparison of room temperature with PCM on the roof and without PCM on the roof

4. CONCLUSION

A detailed study on the incorporation of PCM in building roof is carried out in this work. The incorporation of PCM for space cooling has been achieved. The room temperature is reduced from 35°C to 30°C during daytime and increased from 28°C to 30°C during nighttime. This system is ideally suitable for summer during day time. More research has to be carried to reduce the room temperature during night time in summer. The proposed system is more beneficial for both day and night time during winter season.

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