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Experimental Investigations of PCM Based Thermal Battery for Temperature Management of Building in Hot and Dry Climate of India

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Abstract

This communication investigates thermal behavior of a building with calcium chloride hexa hydrate ($CaCl_2.6H_2O$) as a phase change material (PCM) for thermal management for a hot and dry climate in India. A test room with PCM based thermal battery/thermal management system (TMS) was designed to analyze its thermal performance for the selected location in India. The desired PCM was selected on the bases previously published study and rigorous experimental investigations. To analyze the thermal behavior, the test room with thermal battery was experimentally investigated for 72 kg and 36 kg PCM with evaporative cooler to take the advantage of wet bulb temperature for charging and discharging in the peak summers of a hot and dry climate of the selected location in India. The study showed that selected PCM resulted as a substantial solution for cooling application for hot and dry climateof India.

Keywords: PCM, Thermal Management System, Thermal Battery, Buildings, Hot & Dry Climate.

INTRODUCTION

Thermal comfort in the buildings is one of the major key concerns, as a largest contributor of energy consumption, in this sector. According to the estimated studies by the related agencies, approximately 40 % of the total world`s energy is shared by buildings and 54% of this energy is consumed by heating ventilation and air conditioning only [1,2]. Hence therefore, it has been catching a wider attention due to large potential for energy conservation and limiting CO_2 emissions since last few decades. A significant change can be achieved by better thermal management system to stabilize demand and supply with optimized power consumption. To reduce power consumption, for cooling buildings, thermal energy storage (TES) with phase change materials (PCMs) is utilized as a feasible solution [3-4].

Kuznik et. al. [5] explored an experimental study on the PCM based test room for analysing its thermal comfort. Three walls of the test room was superimposed by a commercial grade encapsulated PCM in the flexible panels of 5 mm thickness. They further recognised a sensible reduction in the indoor test room temperature in the test conducted for two consecutive days using thermal storage system.

Chaiyat [6] investigated improvement in cooling efficiency of a air conditioner in a thermal management system with Rubitherm20 based PCM. The PCM celluloid wall of 40 cm thickness was tested in a 2 TR of R-134a vapor compression air conditioning system. They reported a 3.09 kWhr/day reduction in electricity consumption by the modified thermal management system.

Evola et. al. [7] with the help of case studies investigated various methods for maintaining thermal comfort in lightweight buildings. They explored different parameters such as storage efficiency, frequency of melting, duration and intensity of thermal comfort for maintaining thermal comfort in the summer climate of southern France. They concluded PCM based honey comb structured wall board are more useful for maintaining thermal comfort lightweight buildings.

Sari & Karaipekli [8] performed 1000 thermal tests to identify chemical and thermal stability of fatty acid esters-based composite PCMs and concluded that the PCM is can be employed efficiently in buildings for heat storage.

Lei et al. [9] achieved a 22 – 32% reduction in the heat gain, by the PCM embedded building envelope, in the tropical climate of Singapore throughout the year. In this study they used a thermal management system with phase change material of 28 degree Celsius melting /freezing temperature.

Zhang et al. [10] designed and employed encapsulated PCM wall to reduce peak cooling load for a residential building.The comparison was made for paraffin based PCM frame wall with typical concrete wall showed a significant reduction of 8.6 to 10.8% by adding of 10 to 20%PCM concentrations.

Tyagi et al. [11,12] presented thermal performance for cooling application of the thermal management system using $CaCl_2.6H_2O$ as a PCM with air conditioning system. On the basis of energy and exergy analysis they compared the thermal efficiencies of the PCM based thermal management system for three different heating loads.

Ling et. al. [13] performed an experimental study on indoor conditions of a greenhouse with different parameters such as soil temperature, outdoor air temperature, indoor air temperature, solar radiation and greenhouse envelope surface temperature for 61 consecutive days at Beijing, China. After introduction PCM based thermal management system they observed and effective enhancement in indoor thermal comfort of the greenhouse particularly in sunny weather.

Sharma et al. [14,15] conducted the accelerated thermal test on paraffin wax, stearic acid and acetamide for 300 to 1500 periodic charging-discharging cycles. They further indentified that prafin wax indicated highest thermal stably among all.

The experiment work presents thermal analysis of a PCM, based thermal management system, for cooling application in buildings for hot and dry climate. The selection of $CaCl_2.6H_2O$ as a PCM with $SrCl_2$ as an additive was done based on the detailed study published by Singh & Buddhi. [16]. Based on the previous studies a hot and dry location of India in the peak of the summer was selected by the author for the analysis. It was observed that there is a large variation in the diurnal temperature at the selected location and as far as our knowledge, no studies have been undertaken with PCM to utilize the low ambient temperature of hot and dry climate for thermal management of buildings.

EXPERIMENTAL SETUP AND METHODOLOGY

Experimental Setup

The designed system consists of a test room (made up commercial grade plywood as shown in figure 1) for installation of thermal management system to study the variation of indoor thermal conditions as compared to respective external ambient conditions. High density polyethylene (HDPE) panels filled with commercial grade $CaCl_2.6H_2O$ was used as PCM and $SrCl_2$was used as an additive for required nucleation. An evaporative cooler for charging and draught fan for discharging of PCM was used in the thermal management system. The system configuration of thermal management system is described in the Table 1.The thermal management system was installed at the open environment at the selected hot and dry climate in India. As the variation in diurnal temperature was observed considerably large and the humidity was observed low the night time was preferred for the charging of the PCM. The charging of the PCM was done by the low temperate air of constant mass flow rate maintained by an evaporative cooler of specified capacity. In the day time discharging was done with free and force convection methods with drought fan of specified capacity.

Table 1. System configuration of thermal management system

S.No.	System Descriptions	Numerical values
1.	Test Room	1.7 x 1.2 x 1.2 m
2.	Melting /Freezing Temperature of PCM	27 ^{0}C
3.	Latent Heat of PCM	165 kJ/kg
4.	HDPE panels with PCM	40 & 20 Nos.
5.	Weight of each panel with PCM	1.83 kg
6.	Dimension HDPE panels	300x235x32 mm
7.	Surface area of each HDPE panel	0.172 m^2
8.	Cooler mass flow rate of air	5.6 m/s
9.	Cooler blade diameter	450 mm
10.	Draught fan	15 W A.C
11.	Draught fan mass flow rate	4.7 m/s
12.	Draught fan blade diameter	120 mm
13.	Thermocouples (T-type)	(Copper/constantan), -270 to + 370^{0}C

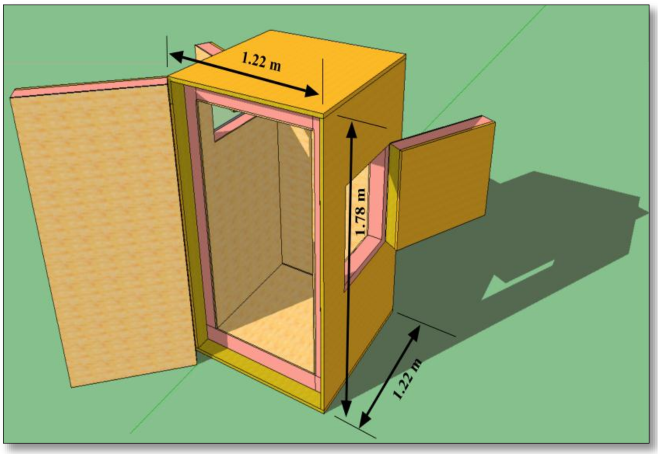

Figure 1. Test room construction and dimensions

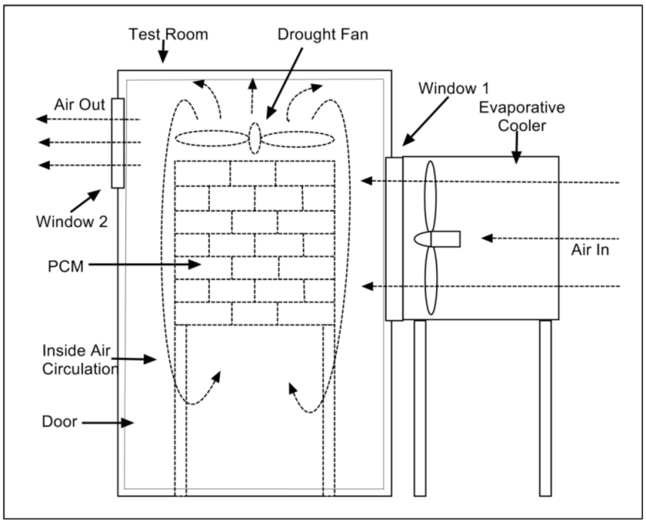

Figure 2. Schematic description of the thermal management system.

Methodology

The designed setup of the test room comprise of 1 door and two windows (for closing or opening when required) was made airtight and equipped with seven calibrated T-type thermocouples (marked as T_1, T_2, T_3, T_4, T_5, T_6 and T_7) at center and inner surfaces of the walls and six calibrated T-type thermocouples (marked as T_8, T_9, T_{10}, T_{11}, T_{12} and T_{13}) at the outer surfaces of the walls and ambient outdoor temperature (marked as T_0) to record the temperature variations as shown in figure 3 and nomenclatures are mentioned in table 2.

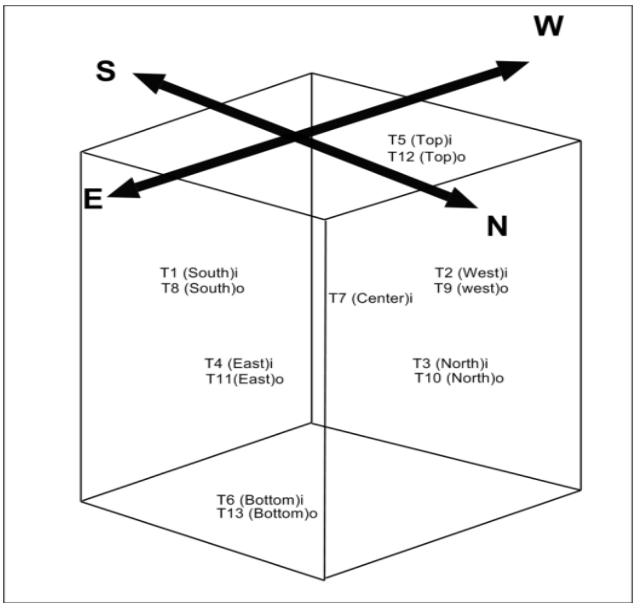

Figure 3. Schematic description of the thermocouples installed in the test room.

Table.2. Nomenclature of the thermocouples.

Nomenclature	Description
T_0	Ambient air temperature in ^{0}C
T_1	Inside surface temperature of south wall in ^{0}C
T_2	Inside surface temperature of west wall in ^{0}C
T_3	Inside surface temperature of north wall in ^{0}C
T_4	Inside surface temperature of east wall in ^{0}C
T_5	Inside surface temperature of top wall in ^{0}C
T_6	Inside surface temperature of bottom wall in ^{0}C
T_7	Inside test room air temperature at the center in ^{0}C
T_8	Inside surface temperature of south wall in ^{0}C
T_9	Inside surface temperature of west wall in ^{0}C
T_{10}	Inside surface temperature of north wall in ^{0}C
T_{11}	Inside surface temperature of east wall in ^{0}C
T_{12}	Inside surface temperature of top wall in ^{0}C
T_{13}	Inside surface temperature of bottom wall in ^{0}C
T_{PCM}	Average temperature of the PCM in ^{0}C

Initially the variation of inner and outer ambient air temperatureof the test room was observed for the two consecutive cycles in 48 hours in the month of May 2018. Global solar radiation, wind velocity and relative humidity were also recorded during the whole span of the experiment.

Thereafter, a well-arranged stack (Shown in the figure 4) of PCM equipped with four T-type thermocouples (marked as T_{15}, T_{16}, T_{17} and T_{18}) was placed inside the test room and average of these all four thermocouples temperature of the PCM was marked as T_{PCM}. The specified capacity of evaporative cooler installed through a firstwindowon one of the walls of the test room for charging of the PCM. Another window on the opposite wall of the first window was provided for maintaining desired ventilation during charging of the PCM. A drought fan of the specified capacity was also installed inside the test room for maintaining force convection during discharging process of the PCM. The observation of the specified parameters was recorded for forced convection charging (10:00 P.M to 5:00 A.M) of the PCM.The window of the test room after charging of the PCM was kept closed and started forced convection discharging (5:00 A.M to 4:00 P.M) of the PCM and the process of charging-discharging was performed for next consecutive cycle in 24 hours, respectively.

Figure 4. Arrangement of PCM Panels.

RESULT AND DISCUSSION

Observations and calculations

Testing conditions (29/05/2018)

The present study deals with analysis of thermal behavior of the test room as compared to ambient conditions with and without PCM. Fig. 5 shows temperature profiles of ambient air, inside test room air, outer test room surfaces and inner test room surfaces from 9:00 P.M to 9:00 P.M (29/05/2018 to 30/05/2018) without PCM. Outside test room surfaces temperature followed ambient temperature profile and inside test room surfaces temperature followed inside test room air temperature profile. The maximum and minimum average temperatures of the outer test room surfaces was recorded as 46.1 and 31.6 ^{0}C against ambient temperature of 46.7 and 31.3 ^{0}C at 3:00 P.M and 5:00 A.M. The maximum and minimum average temperatures of the inside test room air were recorded as 43.1 and 36.3 ^{0}C at 4:30 P.M and 5:00 A.M. The maximum temperature difference between outside and inside test room temperature was recorded as 5.4 ^{0}C at 1:30 P.M. The minimum temperature difference between outside and inside test room temperature was recorded as zero at 5:30 A.M and 7:30 P.M respectively.

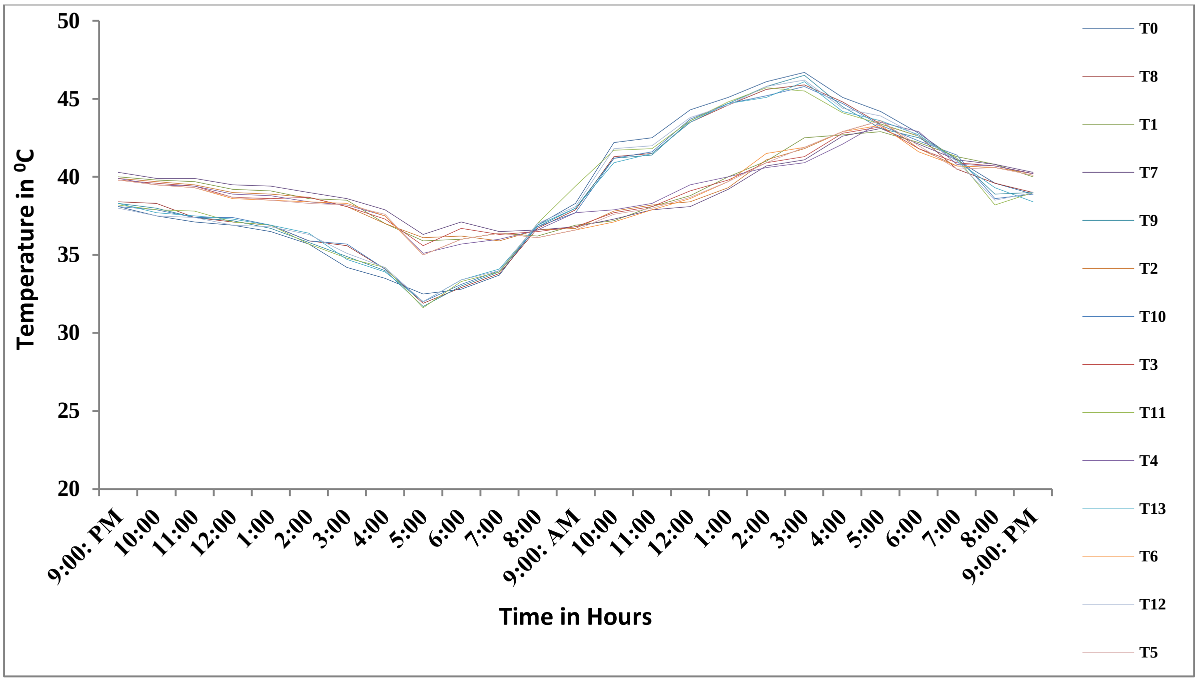

Figure. 5. Temperature profiles of ambient air, inside test room air, outer test room surfaces and inner test room surfaces.

Testing conditions (30/05/2018)

Figure 6 shows charging of PCM (72 kg) from 10:00 P.M to 5:00 A.M. (7 Hrs.) with respect to outer and inner test room air temperatures. The maximum and minimum PCM temperature was recorded as 32.7 and 26.4 ^{0}C at 10:00 P.M and 5:00 A.M. The maximum and minimum temperature ofcooling air was found as temperature 29.1 and 23.1 ^{0}C with an average temperature difference of 2.6 ^{0}C between PCM and cooling air.

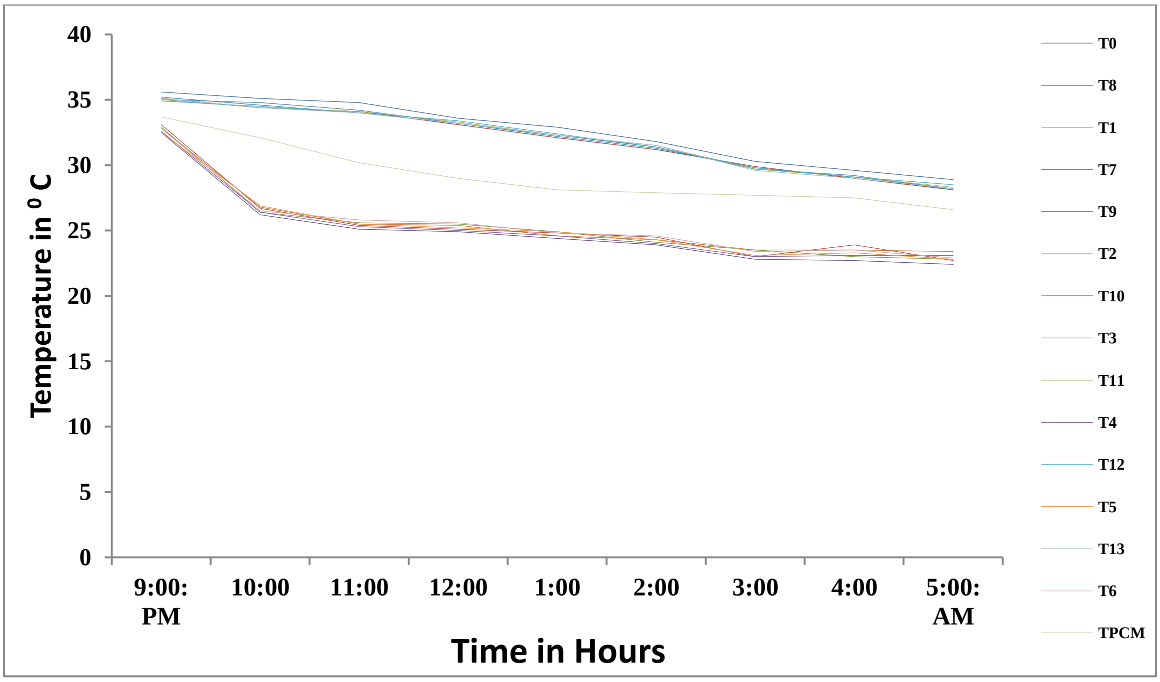

Figure 6. Variation of inside and outside test room temperature w.r.t PCM during charging.

Figure 7 shows discharging of PCM (72 kg) form 5:00 A.M to 9:00 P.M. The maximum and minimum temperature of the inside test room temperature was recorded as 32.3 and 27.4 ^{0}C at 4:30 P.M and 5:00 A.M. The maximum temperature difference between ambient and inside test room air was recorded as 10.9^{0}C at 3:00 P.M and between PCM and inside test room air was 4.5 ^{0}C at 4:30 P.M respectively. It took around 10 hrs.(5:00 A.M to 4:00 P.M) for the complete discharging of PCM under the above mentioned conditions.

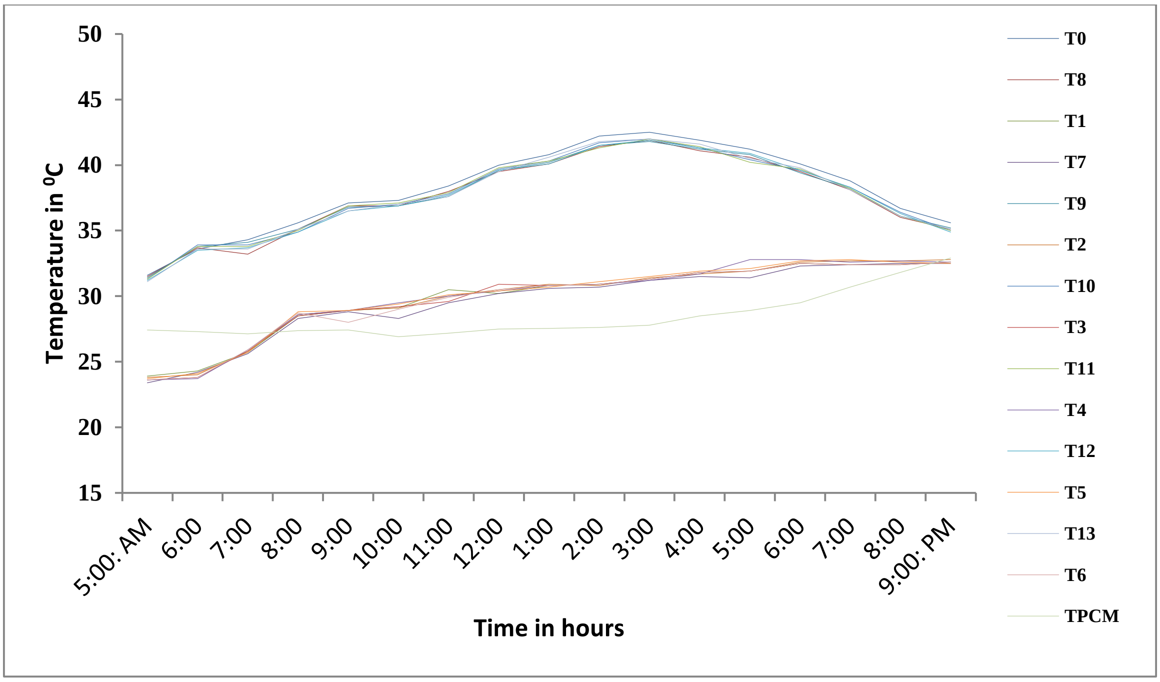

Figure 7. Variation of inside and outside test room temperature w.r.t PCM during discharging.

Testing conditions (31/05/2018)

Figure 8 shows charging of PCM (36 kg) from 10:00 P.M to 5:00 A.M. (7 Hrs.) with respect to outer and inner test room air temperatures. The maximum and minimum PCM temperature was recorded as 33.9 and 26.1 ^{0}C at 10:00 P.M and 5:00 A.M. The maximum and minimum temperature of cooling air was found as temperature 29.6 and 24.1^{0}C with an average temperature difference of 2.8 ^{0}C between PCM and cooling air.

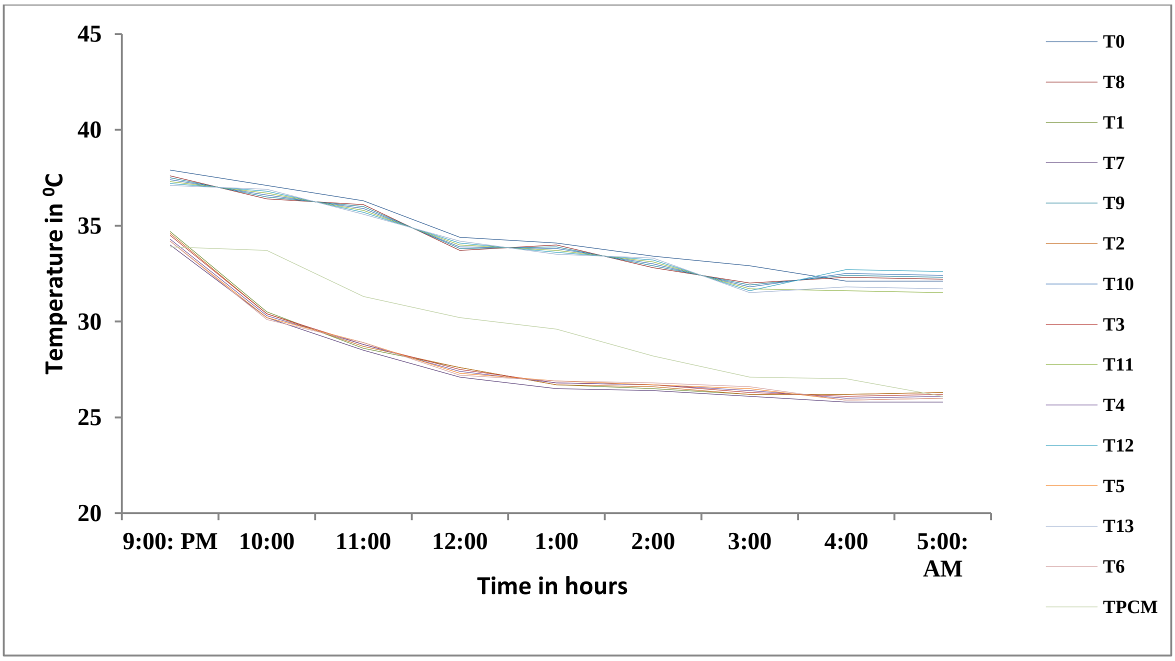

Figure 8. Variation of inside and outside test room temperature w.r.t PCM during charging.

Figure 9 shows discharging of PCM (36 kg) form 5:00 A.M to 9:00 P.M. The maximum and minimum temperature of the inside test room temperature was recorded as 32.9 and 24.1 ^{0}C at 6:00 P.M and 5:00 A.M. The maximum temperature difference between ambient and inside test room air was recorded as 10.1^{0}C at 3:00 P.M and between PCM and inside test room air was 2.4^{0}C at 4:30 P.M respectively. It took around 5.5 hrs.(5:00 A.M to 10:30 P.M) for the complete discharging of PCM under the above mentioned conditions.

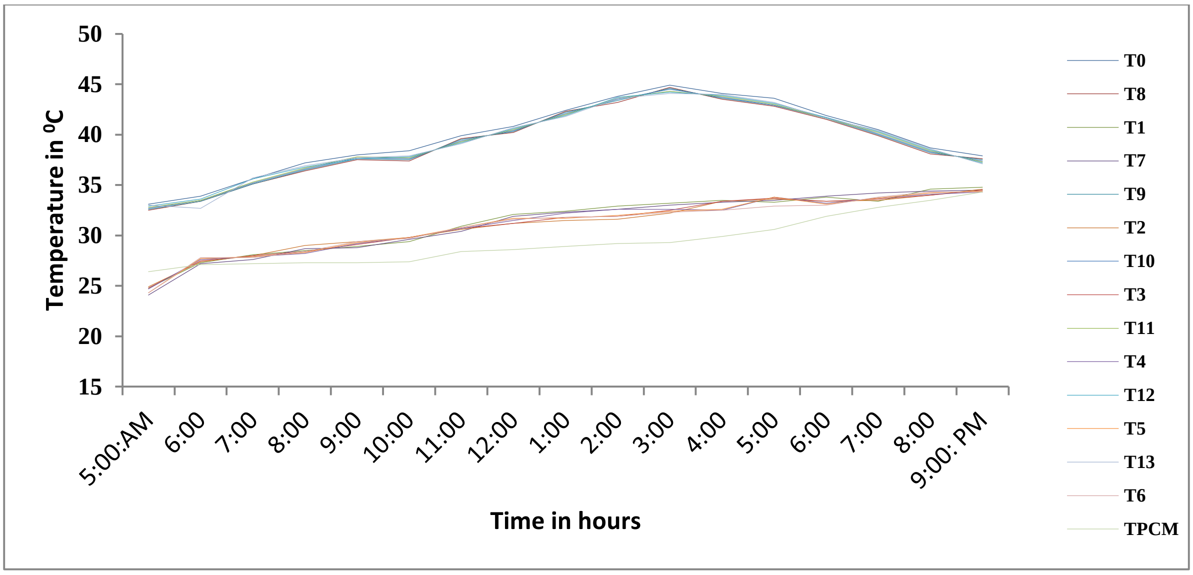

Figure 9. Variation of inside and outside test room temperature w.r.t PCM during discharging.

Comparative analysis of the test room with and without TMS

Temperature variation in test room with and without TMS

A comparative analysis of inside test room temperature withand without TMS is shown in figure 10. Without TMS the maximum temperature (represented as T_7) of test room was observed as 42.8^{0}C at 4:30 P.M. On the other hand, the maximum temperatures (represented as T_{72} and T_{36}) of the test room were recorded as 31.3 and 33.3 ^{0}C at 4:30 P.Mwith 72 and 36 kg PCM based TMS respectively. The average temperature difference between without TMS and with 72 kg PCM based TMS was observed as 9.7 ^{0}C from 6:00 A.M to 4:30 P.M. Thereafter, the average temperature difference between without TMS and with 36 kg PCM based TMS was observed as 8.2 ^{0}C from 6:00 A.M to 4:30 P.M

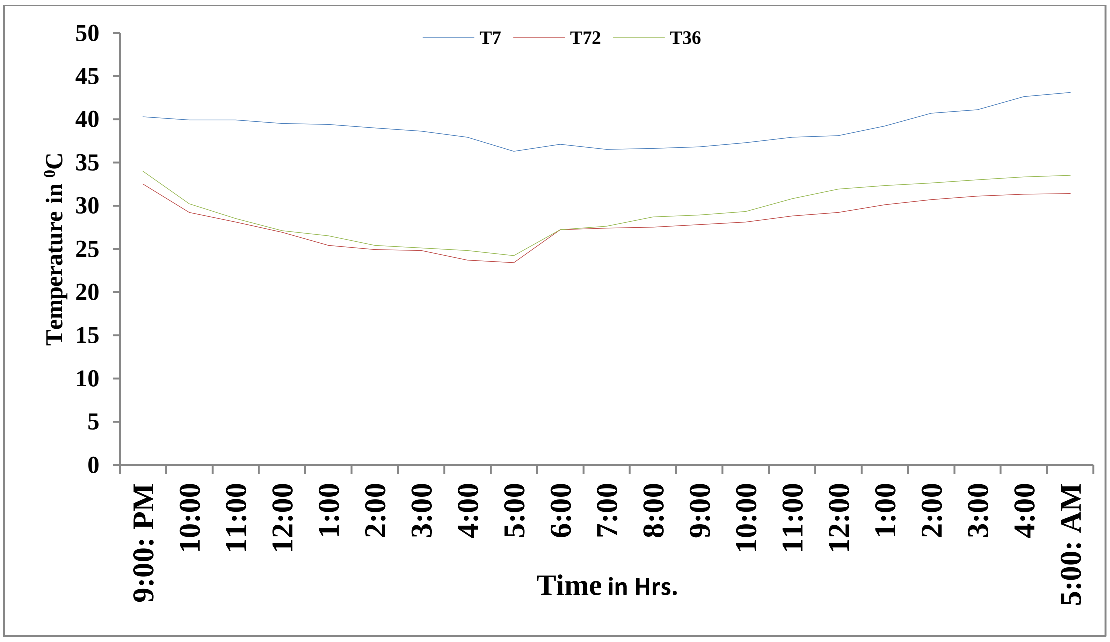

Figure 10. Comparative analysis of inside test room temperature variation with and without TMS

CONCLUSION

The present study deals with analysis of thermal behavior of the test room as compared to ambient conditions with and without PCM. The experiment was performed in three different conditions in the month of May and June at a hot and dry climate of the selected location of India.

Initially, thermal behavior of test room was observed for 24 hours where the maximum and minimum average temperatures of the inside test room was found as 42.8 and 36.5^{0}C against ambient temperature of 46.7 and 31.3 ^{0}C at 3:00 P.M and 5:00 A.M.

Thereafter, the test room was employed with TMS of 72 and 36 kg PCMs. Without TMS the maximum inside temperature of test room was observed as 42.8 ^{0}C at 4:30 P.M. On the other hand, the maximum temperatures of the test room were recorded as 31.3 and 33.3 ^{0}C at 4:30 P.M with 72 and 36 kg PCM based TMS respectively. Hence, it can be concluded that a significant reduction in temperature has been achieved after the introduction of the PCM.

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