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Use of PCM R27 for Thermal Energy Storage in Modular Heat Exchanger for Free Cooling

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Abstract— A Thermal Energy Storage system (TES) has the advantage of an efficient use of energy by reducing the imbalance of an energy demand between daytime and night time. It is classified as sensible and latent heat storage systems. The latent heat storage system is superior to the sensible heat storage system since the former reduces the installation area and the expense due to a large thermal storage capacity and constant phase change temperature during freezing and melting processes. Phase Change Material (PCM) has been used as a medium of energy storage. An experimental investigation is carried out in the present research the setup includes a room of size 8x8x8 feet which is needed to be cooled using the heat exchanger and study the technical feasibility of using R 27 as PCM in a heat exchanger for free cooling applications. The charging and discharging experiments revealed the decline in the PCM temperature from 32°C to 29.5°C. The PCM showed a gradual increase in its temperature from 28°C to 29°C during the discharge process after which the increase was rapid.

Keywords— Latent Heat Thermal Energy Storage; Phase Change Materials; Free cooling; cool energy; Green Buildings; Energy savings; modular heat exchanger.

I. INTRODUCTION

Efficient and economical technology that can be used to store large amounts of heat or cold in a definite volume has been the subject of research for a long time. Latent heat thermal energy storage (LHTES) systems have been gaining importance in such fields as solar energy systems, district heating and cooling systems, energy efficient buildings, cool storage systems for central air conditioning systems, and waste heat recovery systems. There are many LHTES systems used in practical applications. Phase change materials (PCM) are promising candidates for consideration as heat storage media due to their large energy storage capacity. Free cooling is the process of storing the cool energy available in the night time ambient air in a storage device in order to cool the building during the daytime using mechanical ventilation system.

Thermal energy storage systems provide the potential to attain energy savings, which in turn reduce the environment impact related to energy use. These systems provide a valuable solution for correcting the mismatch that is often found between the supply and demand of energy. Latent heat storage (LHS) is a relatively, a new area of study and it received much attention during the energy crisis of late 1970s and early 1980s, when it was extensively researched for use in solar heating systems. When the energy crisis subsided, much less emphasis was put on LHS. Although research into LHS for solar heating systems continues, recently it is increasingly being considered for waste heat recovery, load leveling for power generation, building energy conservation and air-conditioning applications.

As the 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 energy efficient applications. Electrical energy consumption varies significantly during the day and night according to the demand by industrial, commercial and residential activities. In extremely hot and cold countries, the major part of the load variation is due to air-conditioning and domestic space heating, respectively. This variation leads to a differential pricing system for peak and off-peak periods of energy use. Better power generation/distribution management and significant economic benefit can be achieved if some of the peak load could be shifted to the off-peak load period that can be achieved by thermal energy storage for heating and cooling in residential and commercial building establishments.

II. EXPERIMENTAL INVESTIGATION

The experimental setup consists of a cabin of dimension 8 ft x 8 ft x 8 ft and a flat plate modular heat exchanger that contains ten rectangular shape stainless steel panels filled with phase change material. The cabin and the modular heat exchanger are connected through a well-insulated duct and a blower is used to circulate the air through the heat exchanger. A chimney is constructed on the roof top to aid the effect of natural convection. The photographic view of the experimental cabin along with the modular heat exchanger is shown in Fig 1.

Considering the diurnal temperature variation of the Pune city, a suitable PCM with phase transition temperature of approximately 28°C to 30°C is required for charging and discharging. The PCM, RT 27, which is one of the commercial grade PCM available with Rubitherm, is selected for the above-said requirement. The technical specifications of the selected PCM provided by the manufacturer are given in Table 1.

Fig 1: A photographic view of the experimental cabin with the modular heat exchanger

Table 1 Properties of the selected PCM (RT 27)

Melting area	27-29	°C
Congealing area	28 – 25	°C
Latent heat (from 25 to 28°C)	90	kJ/kg
Heat storage capacity	250	kJ/kg
Specific heat capacity	1800 (solid) – 2400 (liquid)	J/kgK
solid Density	870	kg/m3
Liquid Density	750	kg/m3
Heat conductivity	0.2 (solid) – 0.15 (liquid)	W/mK

The flat plate heat exchanger selected in the present study has10 modules which are stacked one over other with 20 mm air gap between each module and it provides a flexible surface area, area/volume ratio. A small fan which is driven by a fan of capacity 0.25kW is used to accelerate the air flow through the heat exchanger during the charging process. Further, this heat exchanger has the facility of controlling the air space between the plates to vary the mass flow rate of air. This heat exchanger offers a very low pressure drop compared to the packed bed arrangement. Considering the above technical advantage, in addition to the ease in construction, a flat plate modular heat exchanger is chosen for the present investigation. The plates are fabricated with stainless steel of grade 304 and the outer casing of the heat exchanger is made of a mild steel plate, with a thickness of 3.5 mm and covered with a 25 mm thick polystyrene insulation. The dimension of the modular heat exchanger is shown in Fig 2, and table 2 shows the details of the modules in the heat exchanger.

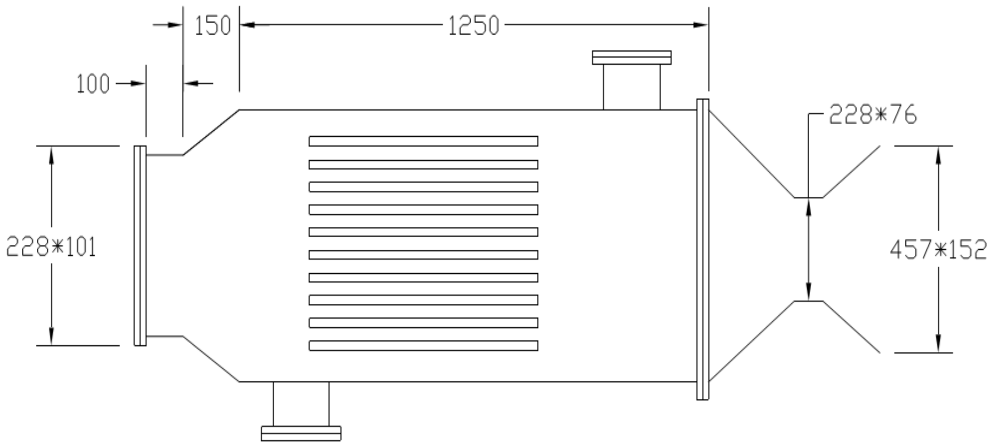

Fig 2. Dimension of the Modular Heat Exchanger

Table 2. Details of the Modular heat exchanger

Module length	0.60 m
Module width	0.30 m
Module thickness	0.030 m.
Volume of one module	$0.0054m^3$
Number of modules	10
Mass of PCM in one module	7.6 kg.

The temperatures of the air at the inlet and outlet of the modular heat exchanger are important parameters for evaluating the energy transfer to the PCM modules. The temperature sensors used to measure the temperature are 2 wire type RTD (PT 100) with a range of 0 – 100°C and an accuracy of ±0.1°C. Two RTDs are kept at the inlet to the room and the average value is considered as outlet temperature of the air from the modular heat exchanger. One RTD is kept near the entry to the modular heat exchanger to measure the inlet air temperature. PCM is measured using the RTDs which are fitted in three locations in three modules of the modular heat exchanger. The average temperature is considered as the PCM temperature. Six RTDs are kept at different locations of the cabin to measure the average interior temperature of the cabin. The temperatures at various locations are monitored continuously, using a data acquisition system, which has an accuracy of ± 0.01°C

The experiments were conducted from 1.30 am in the early mornings during the month of November and December and these duration matches well with the major weather conditions prevailing in Pune city. Several experiments are conducted to study the characteristics of phase change material during the charging process. Air at a mass flow rate of 400 kg/sec is allowed to pass through the heat exchanger. The temperature of the PCM in all the selected locations in the modular heat exchange were noted initially and then the cool air is allowed to pass through the heat exchanger using the fan. The inlet and outlet temperature of air in the heat exchanger, along with PCM temperature in the selected modules are monitored continuously to study the heat transfer performance during the charging process. The experiments were continued until there is an appreciable drop in PCM temperature that ensured the complete solidification of the PCM.

The discharging experiments were conducted followed by the charging experiments. Air at a mass flow rate of 500 kg/sec is allowed to pass through the heat exchanger and this air is entering the cabin. The experiments were commenced from 9.00 am in the morning until there is an appreciable increase in the temperature of the PCM that ensured the complete melting of the PCM. The air inlet temperature, outlet temperature, the PCM temperature and the temperature of the cabin at various RTD locations were monitored continuously. The measurements made at the inlet and outlet of the heat exchanger was used to evaluate the rate of heat transfer during the charging and discharging process.

The instantaneous heat transfer (the rate at which the thermal energy is stored in the PCM) during the charging process is evaluated using Equation (1).

$$Q_{ins} = m_a . c_a (T_{out} - T_{in}) \quad (1)$$

where,

m_a - mass flow rate of the air through the heat exchanger
c_a - Specific heat of air Q_i
T_{in} - Inlet temperature of the air
T_{out} - Outlet temperature of the air

The cumulative heat transfer Q_C is evaluated by integrating the instantaneous heat transfer Q_{ins} considering the constant Q_{ins} value prevails for every 5 minutes duration.

$$Q_c = \sum_{i=0}^{n} Q_i \, dt \quad (2)$$

where,

dt - 5 minutes (300 seconds)
Q_i - Instantaneous heat transfer during i^{th} time.
n -Number of time intervals

III. RESULT AND DISCUSSION

Figure 3 shows the temperature variation of the PCM and the air temperature at the inlet and outlet of the modular heat exchanger. It is seen from the figure that the inlet temperature of the air is around 23 ± 0.75ºC. The PCM which is initially at 32ºC decrease at a faster rate up to 29.5ºC and then the temperature drops at a very slow rate as the PCM releases latent heat and change its phase to solid state. The temperature of the PCM again starts decreasing at a faster rate around 6 am in the morning. This decrease in temperature shows that the PCM in the modular heat exchanger is completely charged. During this charging process the temperature of the air at outlet start decreasing from 30ºC and after duration of 90 minutes the temperature remains almost constant. The initial difference between the air inlet and outlet decreases gradually from 5 to 2ºC.

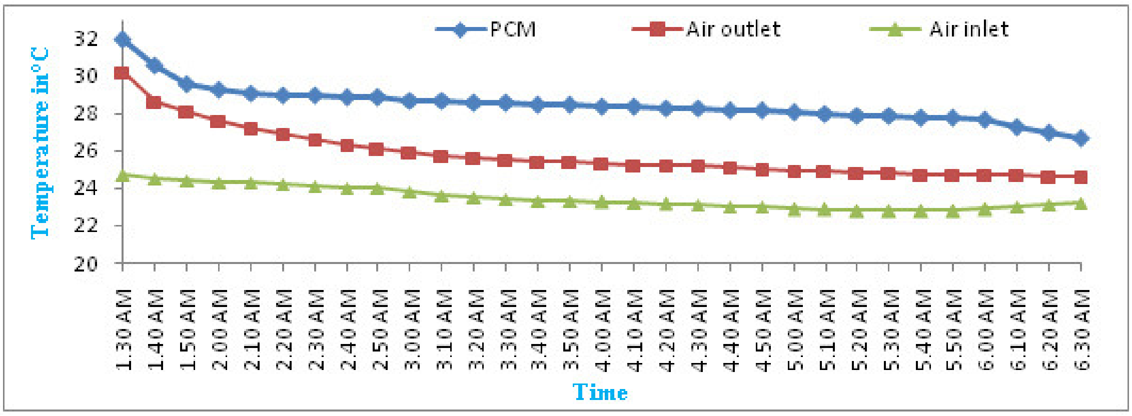

Figure 3. Temperature distribution during charging

Figure 4 shows temperature variation of the PCM, ambient air and the temperature of the cabin where free cool air is circulated through the modular heat exchanger during the discharging process. It is seen from the figure that the ambient temperature varies from 33 to 35ºC during the experiment; the ambient air during its passage through the modular heat exchanger is cooled by absorbing the cool energy from the PCM. The PCM in turn absorbs the heat energy from the air and start changing its phase to liquid state. The PCM temperature slowly changes from 28 to 29ºC with in duration of four hours and then it starts increasing at a faster rate. The cabin temperature decrease from 33ºC and it reaches nearly 31ºC after a time interval of 60 minutes. During this time the ambient temperature is around 34ºC and hence a maximum cooling of 3ºC is achieved inside the cabin after one hour from the start of experiment. This cooling potential of 3ºC is maintained for duration of another 150 minutes and then the cooling potential decreases slowly. It is construed from the figure that the cool energy stored in the PCM is capable of decreasing the cabin temperature by 3ºC from the ambient temperature for a duration of approximately 3 hours and then this cooling potential decreases slowly with respect to time.

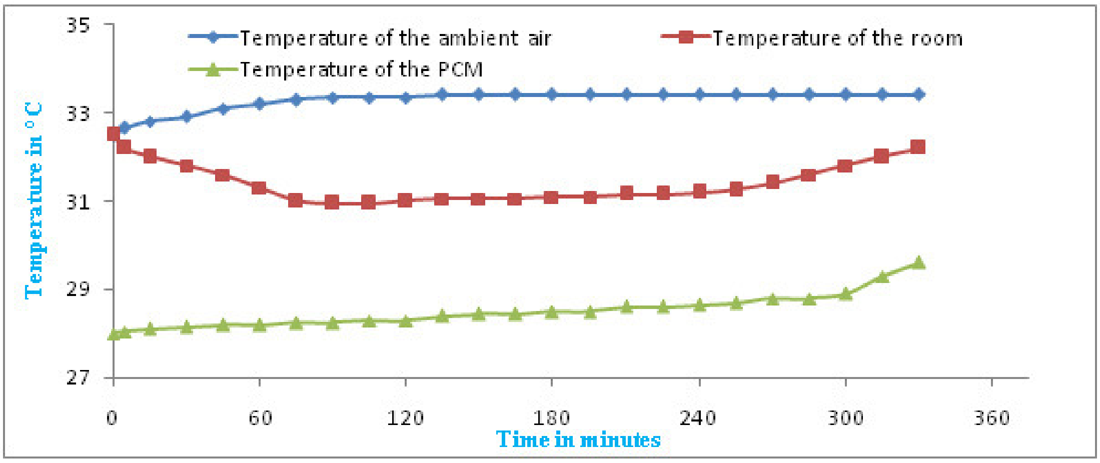

Figure 4. Temperature distribution during discharging

IV. CONCLUSION

It is observed from the literature that there are few cities like Bangalore and Pune in India have large free cooling potential during the several months of the year. Hence an attempt is made in the present investigation for the technical feasibility of free cooling at Pune city by conducting experiments when the ambient conditions at Chennai city matches well with the average ambient conditions that prevails during most of the months in Pune city. It is understood from the various experiments that it is possible to enhance the cooling capacity further through free cooling integrated hybrid passive cooling concept which is presently under investigation. PCM R27 can be effectively used as energy storage mediums for free cooling applications. It has to be chosen wisely considering the heat load and the diurnal temperature variation of the place considered. The material and thickness of insulation provided have a vital role in this process. Insulation has to be made in such a way that the energy has to be stored in the PCM without any loss for about 5-6 hours.

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