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Research Article

Experimental assessment of a PCM to air heat exchanger storage system for building ventilation applications

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Abstract

PCM to air heat exchanger storage system is a solution to store energy in building ventilation system. In this work PCM to air heat exchanger storage experimental system has been developed and tested. The heat exchanger is tested in a open loop which provide constant air flow rates with temperature changes selected such that PCM is allowed to melt & solidify. The PCM used for heat exchanger is paraffin wax. The air velocity during charging and discharging is varied from 0.5 m/sec to 2 m/sec and wattage from 500 W to 1000 W. The results shows that increase in the air velocity leads to decrease the charging time as well as discharging time and thus agitates the charging and or discharging. At 1000 W, charging time reduces by 60 % with increase in air velocity from 0.5 m/sec to 2 m/sec and at same wattage the discharging time reduces by 30% with increase in air velocity from 0.5 m/sec to 2 m/sec. This leads to conclusion that for fast charging and discharging can be achieved by increasing the air velocity.

Keywords: *heat exchanger, PCM, storage unit, heating power*

1. Introduction

Due to the increase of energy costs, buildings energy consumption has been decrease in the last centuries. This gives a opportunity for developing innovative renewable technologies that are modified to recent buildings with small energy demand. In this framework, one main obstacle is to manage availability of heat source or sink and the energy demand of buildings. Hence, various technologies devoted to energy storage have been developed recently; one of them is the use of latent thermal energy storage system using Phase Change Materials (PCM).

Nowadays, thermal energy storage systems (TESS) are essential to decrease the energy organization and the use of environmental energy prospective. Concepts include phase change materials (PCM) are technologically mature for different applications and innovations. Major concepts are used for heating or cooling purposes either for passive or active heating or cooling purposes. The concept is – At initial phase the storage of heat is carried during energy off-peak period. The heating system runs and the heated air pass through the PCM air heat exchanger. By absorbing the heat the phase change material changes its phase from solid to liquid. The material phase is changing from solid to liquid In second phase heating system stops and cold air is blown through the PCM air heat exchanger, where the heat is extracted from the PCM to air and thus heat recovery is possible.

The primary role of buildings is to defend the mankind from the extremities of climates. The complete history of shelter engineering reveals the unremitting effort of the human battle to find enough building designs to which man is best modified. Conventional buildings, therefore, were built with considerations to climatic situation for maintaining the inside building places cool in summer and warm in winter. These aspects have been elapsed in the modern architecture, which fundamentally relies on mechanical and conventional methods of heating and cooling involving large amount of energy expenditure. With the increasing energy emergency there is a transformed interest in those aspects of architecture, which leads to thermal console in buildings without (or with minimum) any expenditure of conventional energy. These aspects are called as solar passive building concept. In addition to it, use of peak power to store the heat or coolness through thermal storage components were also selected up worldwide now a days due to the incentives being provided by the power generation companies.

Principally, thermal energy storage can be proficient either by using sensible heat storage or latent heat storage. Sensible heat storage has been used for large period by builders to store/release passively thermal energy, but a much larger amount of material is required to store the same amount of energy in assessment to latent heat storage. Moreover, concepts including phase change material (PCM) are technically mature for building applications and innovations.

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The general idea behind developing this concept is to develop the PCM air heat exchanger which uses the heat source to charge the PCM air heat exchanger so that the energy can be extracted from the given source which reduces the temperature of the source or alternatively by indirect exchange the temperature of the other fluid cab be increased, which retrieves the heat stored in the PCM air heat exchanger. There is need to develop the experimental which exhibits the behavior of the PCM air heat exchanger during charging and discharging at different air velocities.

2. Literature Review

H. Mehling *et al* tested the heat exchanger in a wind tunnel with constant airflow rates with temperature change chosen so that the PCM is allowed to melt, then to solidify. Temperature and air velocity measurements are achieved for eight airflow rates and the heating power is projected. Outcome show that sufficient energy is stored in the exchanger, On the other hand, the universal behavior of the heat exchanger is simple and can be used as energy storage system.

V.V. Tyagi *et al* conducted experiments to establish the heat transfer characteristics for fully developed flow of air and water flowing in interchange ribbed ducts with an inter-wall spacing equal to the corrugation height. The correlation for friction factor is developed for air channel.

A. Waqas *et al*., Thermal Energy Storage System has become very considerable in the recent years since it balances the energy requirement and improves the efficiency of the solar systems. It is significant that the thermal energy storage systems have the essential characteristics to improve the performance of the storage systems. Usage of Phase change materials for energy storage provides a great advantage but their low thermal conductivity becomes a major disadvantage. This review article gives the recent designs of thermal energy storage systems containing Phase Change Material that has been adopted for successful energy storage.

E. Halawa *et al* developed phase-change energy storage arrangement consisting of sections of various materials with melting temperatures is planned for air conditioning applications. The Phase Change Materials (PCMs) are placed in thin ¯at containers and air is passed through gaps connecting them. The effect of the design parameters such as, PCM slab thickness and fluid passage gap on the storage performance is also evaluated. The system is developed for energy storage space in solar heating and energy efficient space heating and cooling applications.

V. Dubovsky *et al* A complete review of various possible methods for heating and cooling in buildings are reviewed in this paper. The thermal performance of various types of systems like PCM trombe wall, PCM wallboards, PCM shutters, All systems have good potential for heating and cooling in building through phase change materials and also very helpful to reduce the energy requirement of the buildings.

S. Vakilaltojjar..*et al* conducted experimental studies to test thermal cycling of a PCM air heat exchanger at ambient temperatures. The total energy exchanged during melting and solidification, as well as the time over and done until total melting/solidification are determined from the power curves experimentally obtained. The influence of the inlet air temperature and air flow is studied, and results show that the continuous thermal cycling of the unit is a cyclic process: running experiments with similar conditions leads to the same thermal behavior, no decay in the PCM properties is noticed. Pressure drop is measured for different air flows. Depending on the inlet air temperature, full solidification of the PCM could be achieved in less than 3 h for an 8^0C temperature difference between the inlet air and the average phase change of the PCM.

J. Borderon *et al*. carried out a numerical study on the performance of PCM based TES for space heating applications. The storage unit was made of 45 rectangular slabs of length 1m and width 0.89m. Numerical study was conducted with variations in the thickness of the PCM slab and air gaps between the slabs. The PCM used in the slab form is Calcium chloride hex hydrate ($CaCl_2.H_2O$) with melting temperature of 28°C. The results of the experiment shows that the thickness of the slab had strong impact on the heat transfer rates. Thicker slabs reduced the heat transfer rates which led to the augmented melting and freezing time, but with a higher mass flow rate the melting and freezing time was reduced.

P. Dolado *et al* used hot water cylinder to decrease the amount of electricity used for producing hot water .The tubes containing PCM were dimensions of length 0.75 m and 0.04 m diameter placed inside the hot water cylinder of length 1.02 m and 0.474 m insulated with glass wool of thickness 5cm. On examining the results of the different cases, it was found that the PCM in smaller diameter of PVC tubes was melted and solidified faster. The usage of PCM in the hot water cylinder reduces the electricity requirement for heating the water.

S. Vakilaltojjar *et al* experimentally tested the pressure of natural convection on the design and flow parameters of a shell and tube heat exchanger. Two concentric tubes created the heat exchanger. The interior cylinder was 400mm long with internal and external diameters of 15mm and 25mm respectively. The exterior cylindrical tube material and diameters were wide-ranging and investigated, while the shell material was Plexiglas. The tube materials considered for the investigation were copper, stainless steel, and Polyethylene (PE-32). The heat exchanger was insulated with 15mm of arm flex and 30mm of glass wool. Water was used as the PCM and Ethylene glycol-water solution was used as the HTF. Charging and discharging experiments were conducted on the heat exchanger with different values of HTF flow rate and inlet temperature

Campos-Celador *et al*. designed finned plate PCM energy storage for domestic application using RT60 and water. They developed and validated a mathematical model to cover the simulations of the system. The present paper targets only on air-PCM heat exchanger

Zalba *et al*. studied an air-PCM heat exchanger for free-cooling application. They determined the thermo physical properties of two different PCM and developed an empirical model. They showed that this kind of system is technically feasible and economically advantageous.

This works aims to investigate the thermal performance of the PCM air heat exchanger during charging and discharging of heat exchanger at different air velocities. The effect of air velocity on charging and discharging time of PCM air heat exchanger is also evaluated.

2. Experimental Investigation

The experimental investigation has been carried out on developed experimental system to study the behavior of the fin tube type PCM air heat exchanger during charging and discharging of heat exchanger. The details of the experimental system used for this work is as follows.

2.1 Experimental Set up

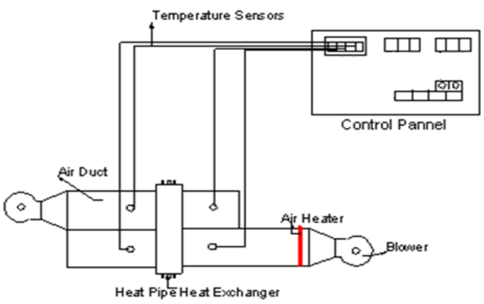

Fig.1 Schematic diagram of the experimental set up.

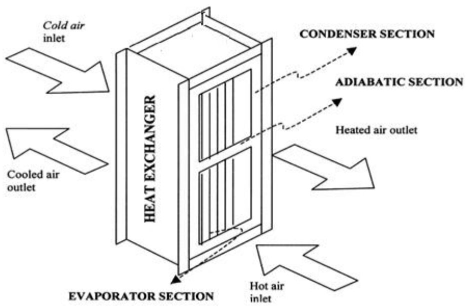

Fig. 2 Schematic of the PCM air heat exchanger

Fig. 1 shows the schematic of overall experimental set up. The experimental system consists of the parallel duct one over another for flow of hot fluid and cold fluid respectively. The PCM air heat exchanger is mounted at center of the duct such that the flow passage for hot and cold fluid is separate. The heated air is produced by passing through the fin tube type electric heater. The amount of the electric energy supplied to the heater can be controlled by controlling the voltage supplied to the heater. The electrical energy supplied to the heater can be calculated from the readings indicated by the voltmeter and ammeter. There is separate passage for cold fluid to downward side. The temperatures sensors are mounted at inlet and outlet of the hot side fluid and cold side fluid. PCM air heat exchanger consists of the copper tubes which are filled with paraffin wax as the phase changer material and both the sides of the tubes are sealed. Fig. 2& 3 gives the schematic of PCM air heat exchanger and actual photograph of the heat exchanger. The blowers are mounted on top as well as bottom side for the flow of the hot and cold fluid at required mass flow rates.

Fig. 3 Actual Photograph of PCM air heat exchanger

2.2 Test Methodology

In order to investigate the thermal performance of PCM air heat exchanger, the heat exchanger charged with hot air as heat source on hot side of heat exchanger. After reaching the temperature of the PCM above transition temperature, the supply of hot air is stopped and cold air at same mass flow rate as that of hot air mass flow rate is passed through the cold side of heat exchanger thus charging and discharging characteristics of a PCM air heat exchanger has been evaluated. Two types of tests have been carried out on the PCM air heat exchanger:

- Charging of the PCM, which changes the state of the PCM from solid state to liquid state.
- Discharging of the PCM, which changes the state of the PCM from liquid state to solid state.

The charging of heat exchanger has done by passing the cold air over the fin tube type heater at a decided wattage, which gives out the hot air which then passes through the PCM air heat exchanger. The wattage to heater is varied from 500W to 1000 W in step of 250W. The velocity of air passing through the PCM air heat exchanger is varied from 0.5 m/sec to 2 m/sec in the step of 0.5 m/sec. It has been taken in to consideration that the at a particular wattage the same velocity is maintained for hot air and cold air during charging and discharging process of heat exchanger. The variation of the PCM temperature has been recorded at a different time interval during charging and discharging process of heat exchanger. The temperatures are measured with temperature sensors (RTD) which are inserted in the PCM tubes on hot side and cold side of heat exchanger. Then average temperatures of PCM have been evaluated from hot side during charging and cold side during discharging. Air velocity is measured with the help of air vane anemometer on hot side and cold side of PCM air heat exchanger.

Table 1. Test parameters

Parameter	Description
Heat load (W)	250 W to 1000 W
Source temperature(0C)	70 to 120 0C
Velocity (m/sec)	0.5 to 2 m/s

2.3 Performance Parameters

The performance of PCM air heat exchanger have been evaluated in terms of the time required for charging and discharging of the PCM air heat exchanger by supplying the heat exchanger with different source temperature for charging and cold air for discharging at constant velocity. Additionally the variation of the PCM temperature during charging and discharging process has been recorded. The variation of the charging and discharging time with variation in the hot air flow velocity and cold air flow velocity has also been recorded.

3. Objectives

A study carried out to assess the free cooling potential for India and it is possible to eliminate totally a mechanical air conditioner. Considering the potential and also the need for the demonstration setup, the major objectives of the present work are formulated as below:

- To develop a PCM based storage type heat exchanger suitable for free cooling applications of buildings.
- To investigate the charging characteristics of the PCM under various ambient conditions that prevails during the early-morning hours.
- To determine the temperature reduction possible with the present heat exchanger under various inlet conditions.

4. Results and Discussions

The variation of the PCM temperature during charging and discharging of the PCM air heat exchanger and charging and discharging time at different wattage and different air velocities are as shown below.

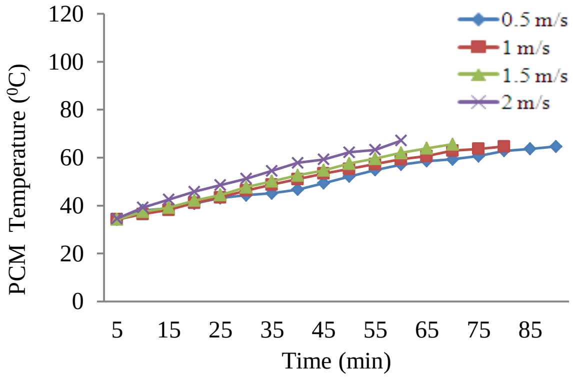

Fig. 4. Variation of PCM Temperature with time during Charging at heat input 500 W

Fig. 4 shows the variation of the PCM temperature with time during charging the PCM air heat exchanger at different air velocities at 500 W. The graph shows that with increase in the air velocities, time required to reach the predetermined temperature reduces. At a given time the higher velocity gives the maximum temperature of the PCM during charging of the PCM.

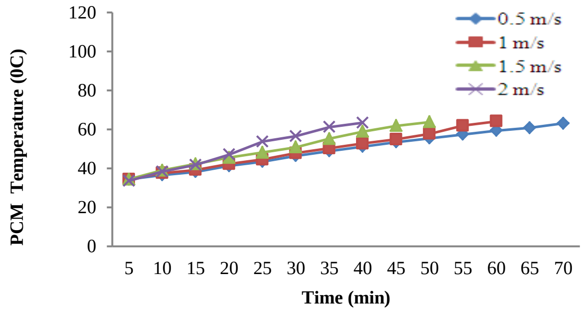

Fig. 5. Variation of PCM Temperature with time during Charging at heat input 750 W

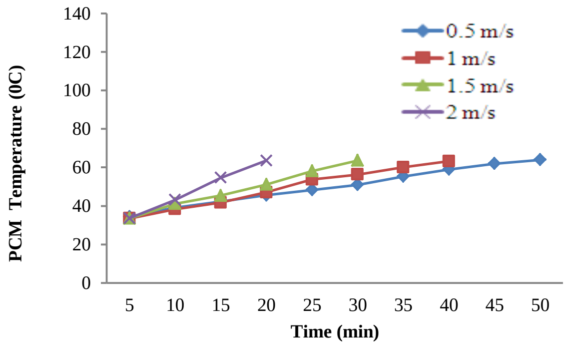

Fig. 6. Variation of PCM Temperature with time during Charging at heat input 1000 W

Fig. 5 & 6 shows the variation of the PCM temperature with time during charging the PCM air heat exchanger at different air velocities at 750 W and 1000 W respectively. The graph shows that with increase in the air velocities, time required to reach the predetermined temperature reduces. At a given time the higher velocity gives the maximum temperature of the PCM during charging of the PCM. With increase in wattage, time required to reach the certain temperature is reduced.

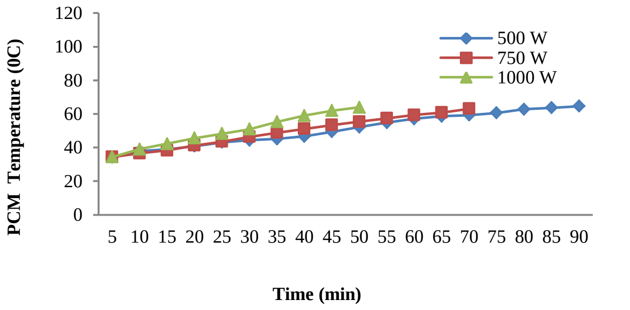

Fig. 7. Variation of PCM Temperature with time during Charging at air velocity 0.5 m/s

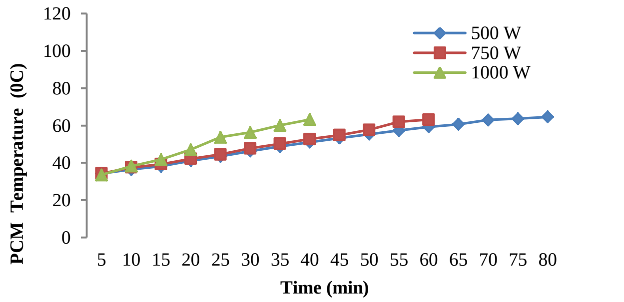

Fig.8. Variation of PCM Temperature with time during Charging at air velocity 1 m/s

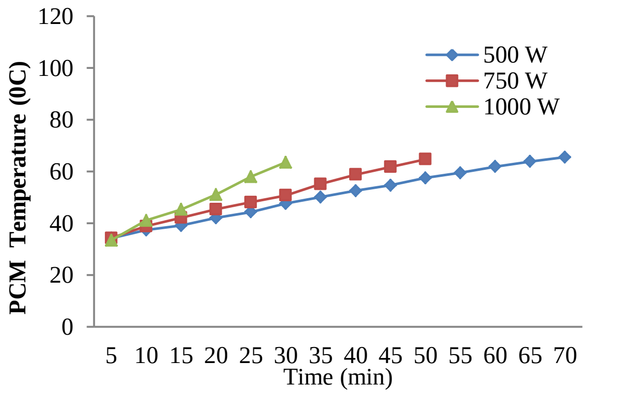

Fig. 9. Variation of PCM Temperature with time during Charging at air velocity 1.5 m/s

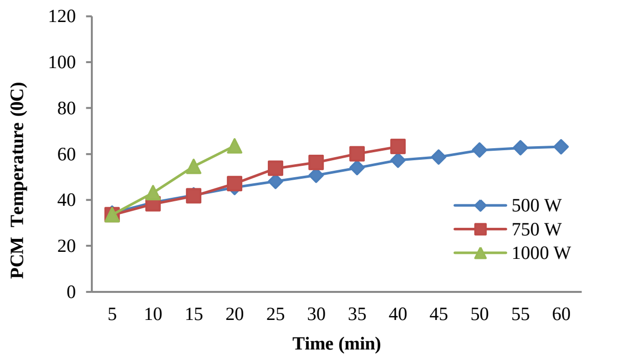

Fig. 10. Variation of PCM Temperature with time during Charging at air velocity 2 m/s

Fig. 7 to 10 shows the variation in the PCM temperature with time at different wattages during charging for air velocity ranges from 0.5 m/sec to 2 m/sec. The graph shows that with increase in the wattage time required to charge PCM air heat exchanger is reduced.

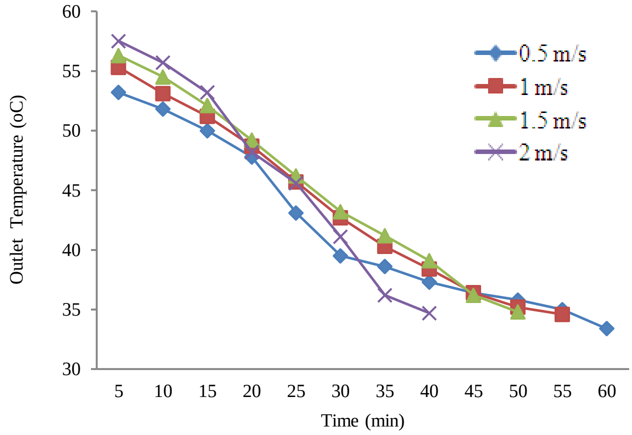

Fig 12. Variation of cold air outlet temperature with time during Discharging at heat input 750 W

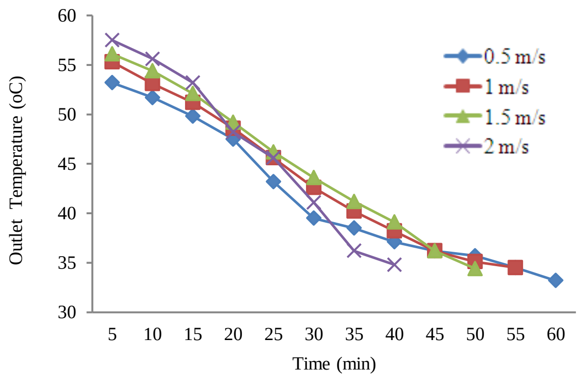

Fig. 13. Variation of cold air outlet temperature with time during Discharging at heat input 1000 W

Fig. 11 to 13 shows the variation of the PCM temperature with time during discharging the PCM air heat exchanger at different air velocities at 500 W to 1000 W respectively.. The graph shows that with increase in the air velocities, time required to reach the predetermined temperature reduces. At a given time the higher velocity gives the minimum temperature of the PCM during discharging of the PCM.

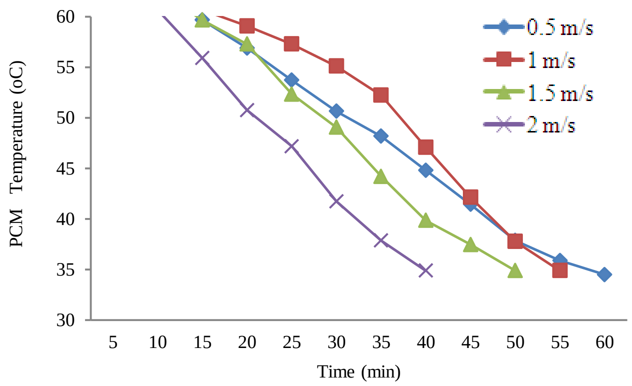

Fig. 14. Variation of PCM Temperature with time during Discharging at heat input 500 W

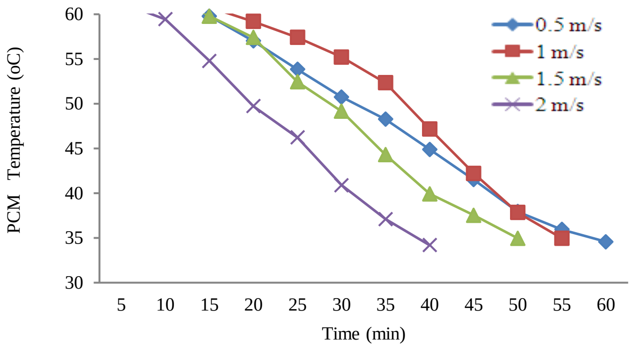

Fig. 15. Variation of PCM Temperature with time during Discharging at heat input 750 W

Fig. 14 to 16 shows the variation in the PCM temperature with time at different wattages during discharging for air velocity ranges from 0.5 m/sec to 2 m/sec. The graph shows that with increase in the wattage time required to discharge PCM air heat exchanger is reduced. Thus in general the fast charging or discharging can be achieved by blowing the hot or cold air through the PCM air heat exchanger at higher velocities or by increasing the source temperature.

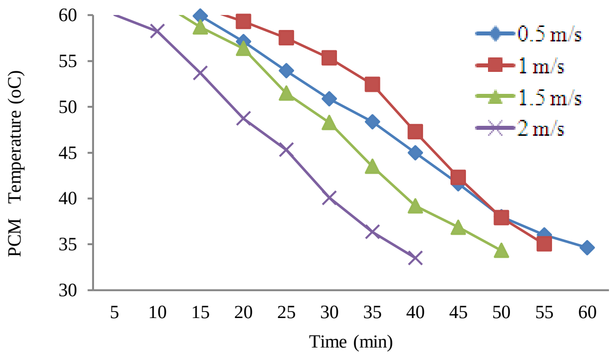

Fig. 16. Variation of PCM Temperature with time during Discharging at heat input 1000 W

Conclusions

Following conclusions can be drawn from the work carried out in context of the charging and discharging of PCM air heat exchanger for building ventilation applications with paraffin wax as the phase change material.

1) The charging behavior of the PCM air heat exchanger with variation in air flow velocity and electrical energy supplied to the heater is studied. The results shows that increase in the air velocity and electrical energy supplied to the heater leads to decrease the charging time and thus agitates the charging.

2) The discharging behavior of the PCM air heat exchanger with variation in air flow velocity and electrical energy supplied to the heater is studied. The results shows that increase in the air velocity and electrical energy supplied to the heater leads to decrease the discharging time and thus agitates the discharging.

3) At 1000 W, charging time reduces by 60 % with increase in air velocity from 0.5 m/sec to 2 m/sec and at same wattage the discharging time reduces by 30% with increase in air velocity from 0.5 m/sec to 2 m/sec. This leads to conclusion that for fast charging and discharging can be achieved by increasing the air velocity.

4) The proposed work can be applied for building ventilation purpose with which inside hot air can be blown through the heat exchanger and re-circulated again and again such that inside room temperature can be maintained at lower side. On the other hand the external heat source can be utilized to charge the heat exchanger and as and when required the same stored heat can be retrieved from heat exchanger.

5) The proposed work can be compared to another PCM material that is nothing but Paraffin 28-Carbons and checking the results for same.

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