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EXPERIMENTAL INVESTIGATION OF PCM-AIR HEAT EXCHANGER FOR BUILDING VENTILATION SYSTEM

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Abstract

Many researchers investigated on the performance of PCM heat exchanger for latent heat energy storage. Now it's a need of time to develop an experimental investigation which indicates the results in a simplest manner so that we can predict the results within the acceptable range of numerous results. In this work PCM to air heat exchanger storage experimental system has been developed and tested. The PCM heat exchanger is tested in a constant air flow rates with variant temperature ranges such that PCM is allowed to melt & solidify. The PCM used for heat exchanger is PCM-60(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 result shows that increase in the air velocity is inversely proportional to charging as well as discharging time. 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 2m/sec. This leads to conclusion that fast charging and discharging of PCM heat exchanger can be achieved by increasing the air velocity.

Keywords: *Phase change material, PCM heat exchanger.*

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.[1]

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.[3]

The rapid economic growth in some of the fast-developing nations has stimulated the utilization of sustainable energy sources and energy conservation methodologies. Globally, buildings are responsible for approximately 40% of the entire world's annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling and air conditioning. The growing trend in building energy consumption will continue during the coming years, due to the expansion of the built area and the associated energy needs, as long as the resources and environmental exhaustion or economic recession allows it. Air-conditioning systems are used to control the temperature, moisture content, circulation and purity of the air within a space, in order to achieve the desired effects on the occupants. Recognizing the need to save energy and minimize the green house gases, efforts are being made to increase the awareness and importance of reducing building energy use. Hence, the research related to passive and energy-efficient cooling and heating methodologies in buildings is important. The details of various passive cooling techniques, free cooling concept, and the use of thermal energy storage systems for energy management in buildings, are explained in the following sections.[7]

2. Thermal Energy Storage

Thermal Energy Storage (TES) can be generally classified as sensible heat storage and latent heat storage, according to the heat storage media. In sensible heat storage, the heat is stored or released accompanied by the temperature change of the storage medium, whereas in latent heat storage, the heat is stored or released as the heat of fusion / solidification during the phase change processes of the storage medium. By contrast, latent heat storage with phase change materials provides a high-heat storage density, and has the capability of storing a large amount of heat during the phase change process, with a small variation of the PCM volume and temperature. Using latent heat storage in buildings can meet the demand for thermal comfort and energy conservation purposes[9]. Thermal energy storage systems can play an important role as they provide great potential for improved energy efficiency, and they are a necessary component for the efficient utilization of renewable energy sources and for energy conservation. A good design of latent heat thermal energy storage requires the knowledge of PCMs and the heat exchange processes, especially the melting and solidification processes in a containment. A latent heat thermal storage system has the following three main components: (i) a PCM suitable for the desired temperature range; (ii) a container for the PCM (encapsulation of PCMs); and (iii) a heat exchange surface required for transferring the heat from the heat source to the PCM and from the PCM to the heat sink.

3. Literature Review

3.1 Passive cooling techniques

Ong (2011) reported that the heat transmission through the roof could be reduced by providing insulation in the attic under the roof or above the ceiling. A roof solar collector could provide both ventilation and cooling in the attic. Several laboratory-sized units of passive roof designs were constructed and tested side-by-side under outdoor conditions to obtain the temperature data of the PCM wallboard is considered to be an effective and less costly replacement of the standard thermal mass, to store solar heat in buildings, in which the PCM is embedded into a gypsum board, plaster or other building structures.[1]

Neeper (2000) impregnated fatty acid and paraffin waxes into the gypsum wallboard and examined the thermal dynamics under the diurnal variation of the room temperature (the radiation absorbed was not considered) with the PCM on the interior and exterior portions respectively. Their investigation indicated that when the PCM's melting temperature was close to the average room temperature, the maximum diurnal energy storage occurred and diurnal energy storage decreased if the phase change transition occurred over a range of temperature.[2]

Heidarinejad et al (2010) studied a hybrid system of nocturnal radiative cooling, and direct evaporative cooling in Teheran. This system complements direct evaporative cooling, as it consumes low energy to provide cold water, and is able to fulfill the comfort conditions, whereas direct evaporative alone is not able to provide summer comfort conditions, and the results showed that the overall effectiveness of the hybrid system is more than 100%.[3]

3.2 Free cooling potential

Medved and Arkar (2008) studied the free-cooling potential for different climatic locations in Europe. The size of the LHTES was optimized on the basis of the calculated cooling degree-hours. Six representative cities were selected in Europe that covers a wide range of different climatic conditions. Numerical investigations of the free-cooling potential were made for a time period of 3 summer months.[4]

H. Mehling et al. (2008) 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.[6]

V.V. Tyagi et al. (2007) 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.[7]

A. Waqas et al. (2013) 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.[8]

4. Phase Change Material

Phase Change Material (PCM) is a substance with a high heat of fusion, which melts and solidifies at certain temperatures, and is capable of storing or releasing large amounts of energy. The only phase change used for storing energy is the solid-liquid change. Liquid-gas PCMs are not practically suitable for thermal storage, due to their large volumes or high pressure requirement, to store the materials in a gaseous phase.

4.1. Behaviors of PCM

Initially, the solid-liquid PCMs perform like conventional storage materials. The temperature rises as they absorb heat. However, when the PCMs reach the temperature at which they change phase, they absorb large amounts of heat without a significant rise in the temperature. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. Some PCMs are very effective within the human comfort range of 20°C to 30°C. They store 5 to 14 times more heat per unit volume than conventional storage materials, such as water, masonry or rock.[5]

For the use of PCMs in free cooling applications, the following requirements, relating to the phase change temperature, must be fulfilled. The melting temperature must be close to the system's operative temperature range. This means that the phase change temperature must be close to room temperature. It must be lower than the highest acceptable room temperature. The melting temperature range of the PCM must be within an acceptable range. Otherwise, the function of the system is jeopardized. It must be possible to solidify the material with the night outdoor temperature[6]. The phase change temperature is an important property of the PCM. For change of thermal inertia using cool night air, a melting temperature close to room temperature is suitable. The melting temperature cannot be too low, because it must be possible to solidify the PCM with the outdoor night air. The long term stability of the PCMs is required by the practical applications of latent heat storage, and therefore, there should not be major changes in the thermal properties of the PCMs after undergoing a great number of thermal cycles.

4.2. Selection criteria

The PCM to be used in the design of a thermal storage system should possess desirable thermo physical, kinetic and chemical properties that are recommended as follows.

(i) Thermo-physical properties

- Melting temperature should be in the desired operating temperature range (temperature range of application).
- High latent heat of fusion per unit volume so that the required volume of the container to store a given amount of energy is smaller,
- High specific heat to provide additional significant sensible heat storage.
- High thermal conductivity of both solid and liquid phases to assist the charging and discharging energy of the storage system.
- Small volume change on phase transformation and small vapors pressure at operating temperature to reduce the containment problem.
- Congruent melting of the phase change material for a constant storage capacity of the material with each freezing / melting cycle.

(ii) Kinetic properties

- High nucleation rate to avoid super cooling of the liquid phase.
- High rate of crystal growth, so that the system can meet the demand of heat recovery from the storage system.

(iii) Chemical properties

- Complete reversible freeze / melt cycle,
- No degradation after a large number of freezes / melt cycles.
- No corrosiveness to the construction materials, Non toxic, non-flammable and non-explosive material for safety.

5. Experimental Investigation

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 rate.

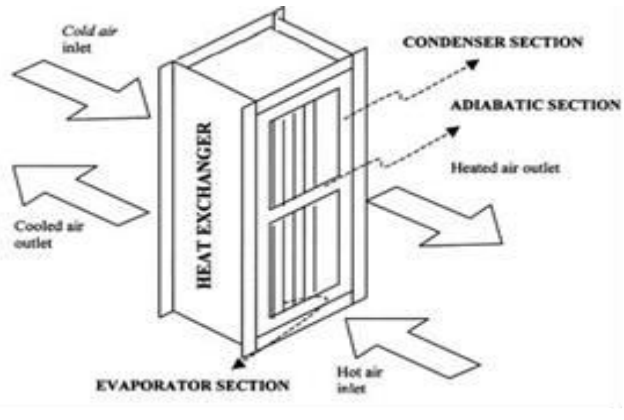

Fig. 1 Schematic of the PCM air heat exchanger.

5.1 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)	500 W to 1000 W
Source temperature(0C)	70 to 120 0C
Velocity (m/sec)	0.5 to 2 m/s

6. 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.

6.1. Variation of PCM Temperature with time during Charging at different heat input:

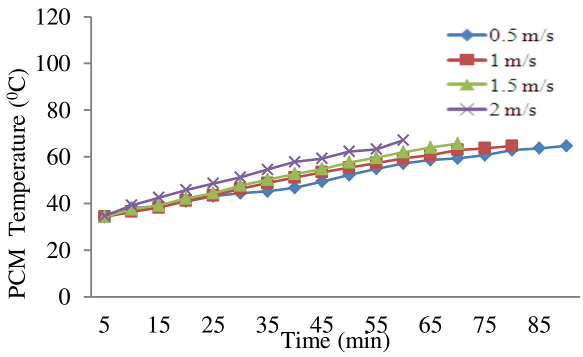

Fig. 2 Variation of PCM Temperature with time during Charging at heat input 500 W

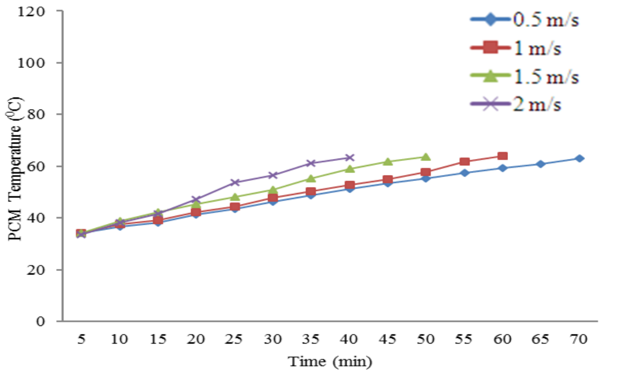

Fig. 3 Variation of PCM Temperature with time during Charging at heat input 750 W

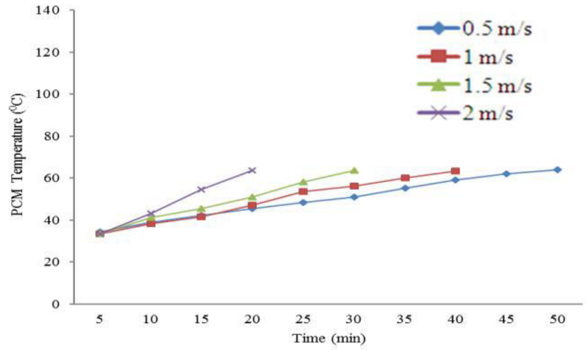

Fig. 4 Variation of PCM Temperature with time during Charging at heat input 1000 W

Fig. 2 to 4 shows the variation of the PCM temperature with time during charging the PCM air heat exchanger at different air velocities at 500 W to 1000W. 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.

6.2. Variation of cold air outlet temperature with time during Discharging at different heat input:

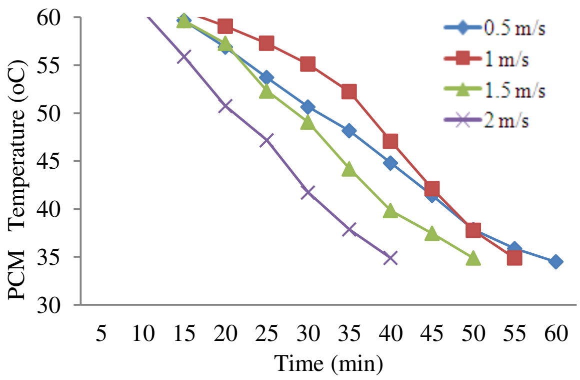

Fig. 5 Variation of cold air outlet temperature with time during Discharging at heat input 500 W

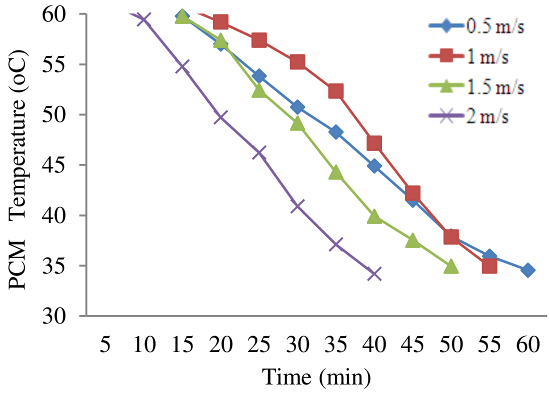

Fig. 6 Variation of cold air outlet temperature with time during Discharging at heat input 750w

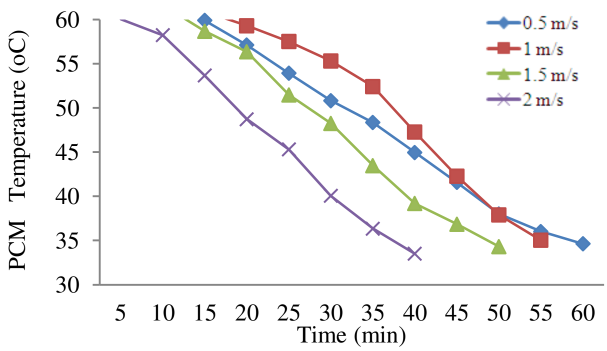

Fig. 7 Variation of cold air outlet temperature with time during Discharging at heat input1000w

Fig. 5 to 7 shows the variation of the PCM temperature with time during discharging the PCM air heat exchanger at different air velocities at 500 W to 1000W 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.

Conclusions

We get the following conclusions from the work carried out in context of the charging and discharging of PCM air heat exchanger for building ventilation system with pcm-60 as the phase change material.

[1] The experimentation carried out to study the charging behavior of the PCM air heat exchanger with variation in air flow velocity and electrical energy supplied to the heater. 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] Here we studied the discharging behavior of the PCM air heat exchanger with variant air flow velocity and electrical energy supplied to the heater. The results shows that increase in the air velocity supplied to the heater leads to decrease the discharging time and thus agitates the discharging.

[3] 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.

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