EXPERIMENTAL ANALYSIS OF COLD THERMAL ENERGY STORAGE SYSTEM FOR COOLING APPLICATIONS

Anish R[1], S.R Karale[2]

[1]M-Tech, Heat Power Engineering student, [2] Asst. Professor,
Department Of Mechanical Engineering,
GHRCE Nagpur, RTM Nagpur University, Maharashtra, (India).

ABSTRACT

Thermal energy storage is one of the key technologies for energy conservation, and therefore, it is of great practical importance. Thermal energy storage systems are designed to produce the necessary cooling effect during peak hours by utilising the advantage of cheaper electric utility rates during normal hours. This thesis investigates the effects of various design factors like mass flow rate of air, selection of materials for the coolant and storage medium for the optimal usage of an energy storage system that lowers operating costs while providing adequate occupant comfort conditions in commercial application. The basic operating strategy of the Thermal Energy Storage systems is to reduce peak time energy consumption. Energy is stored during normal hours and this stored energy is utilised during the peak time. Water, calcium chloride is used as Phase Change Materials and ethyl alcohol, glycol as coolants for the proposed Thermal energy storage system. Analytical study was carried out on the system to measure its effectiveness based on the cooling effect and temperature variation. Further, the system was fabricated based on the design and comparative study was performed keeping in mind the factors like consistency of performance, suitability and availability of working fluids and PCM's. From the works performed, adoption of energy storage based air conditioning systems have proven to be cost effective from a consumer's perspective, if different electricity tariffs are available for the peak and normal hours.

***Key Words:* Cold Thermal Energy Storage Systems, Cooling System, Phase Change Materials, Peak Time Energy Savings, Refrigeration System.**

I INTRODUCTION

Energy is the backbone of human activities and the increment in global energy demands due to population growth and 20th century industrial revolution leads fossil fuels through a transitional phase. Since sustainability is becoming more important than ever in societies as the limits of our ecosystem become clearer and clearer.With the shift of focus in the energy industry towards more efficient and sustainable generation, transmission and usage of power, reducing waste has become an important area of research and development.Thermodynamics teaches us that all process inefficiency eventually manifests itself as thermal energy. In most processes, excess thermal energy is released to the atmosphere or a large body of water to complete a cyclic process or prevent overheating of components or facilities.

Although excess thermal energy is impossible to completely eliminate, it has the potential to be harvested and used for applications that would otherwise require additional energy input from other sources. This method of energy transfer is not presently widely employed for several reasons. The two most significant of these are that the industry or utility that is producing the excess thermal energy is often not able to use it all at the time it is available, and that creating thermal energy from combustion of fossil fuels has historically been inexpensive. This means that recovering unused thermal energy does not decrease the energy usage of the system the designer is concerned with, their own facility, and low fossil fuel prices do not motivate others to seek alternate sources of thermal energy. An increase in overall system efficiency from excess thermal energy recovery would only be seen on a much larger scale in most instances, when the system analysed is a community or region and the energy inputs from all sources are considered.

Due to lower fossil fuel prices, there is presently no thermal energy market to encourage the harvest and trade of excess thermal energy. The transfer of thermal energy as a commodity would minimize the traditional thermal energy generation requirements, including the use of electricity and the chemical energy in fossil fuels to supply the heating and cooling requirements of residential and industrial customers. Locating and quantifying the production and utilization of thermal energy on a regional scale would allow a more comprehensive energy system model to be developed in order to identify potential efficiency improvements in various communities. It would also allow for small and large thermal energy recovery systems to be used such that thermal storage and transport can be accomplished on all scales. A new study on energy efficiency in buildings (EEB) indicates that the global building sector needs to cut energy consumption in buildings 60 per cent by 2050 to help meet global climate change targets. According to the World Business Council for Sustainable Development (WBCSD), buildings account for 40 percent of the world's energy use with the resulting carbon emissions.

Renewable sources as solar energy are the potential candidates for sustainability. The sun is a powerful source of energy. More energy from the sun falls on the earth in one hour than is used by everyone in the world in one year. But then the limitations of the source turn up. The amount of sunlight that arrives at the earth's surface is not constant. It varies depending on weather conditions, location, time of year, time of day. The sunshine and peak demand normally does not coincide, people come home from work around sunset and turn on their space heating systems and peak demand continues long after sundown. A system that relies heavily on an intermittent source of power needs an efficient thermal storage. Thermal solar storage is promising to cover domestic hot water and space heating demand but still need auxiliary energy to cover the whole demand.The project at hand is a study about thermal energy storage (TES) based on latent heat storage. TES provides a solution to correct the mismatch between the supply and the demand for energy. High capacity storage applications can be done with Phase Change Materials (PCM). The advantage of using a PCM is that energy can be stored without temperature increase when the material is going from solid to liquid form.

II EXPERIMENTATION & METHODOLOGY

Fig: shows the schematic diagram of the experimental setup,
Experimental setup can be divided into two parts as follows.

1) Charging System.
2) Discharging System

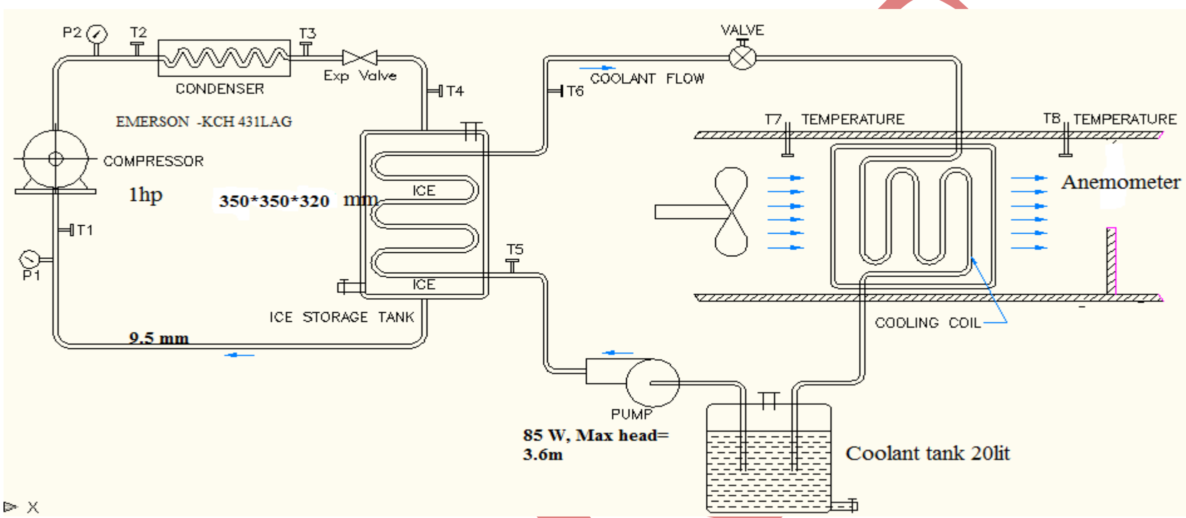

Fig.1 Experimental setup

Proposed Experimental setup is thermal energy storage based cooling system. Energy is stored during normal hours and this stored energy is utilised during the peak time. Water,glycol and calcium chloride is used as Phase Change Materials and ethyl alcohol, glycol as coolants for the proposed Thermal energy storage system. The aim of this project is to use the latent heat energy storage of phase change materials for room cooling. . Same quantity of PCM s are used for experimental purpose. In the proposed project heat of fusion of Cacl2 .6H2o/ water/glycol as the PCM is used for cooling coolants like glycol and ethyl alcohol And these cooled coolants are used as circulating medium trough cooling duct. Air through the cooling duct will get cooled by transferring heat to coolants and fresh & cool air will be thrown in a room.

III RESULTS & DISCUSSION

The series of experiments were carried out on the experimental test rig. The temperature profile of the cooling system was tabulated and charted to be used in the evaluation of the thermal performance. Different PCM and coolant combinations were used for the study. Same quantity PCM s(40 kg Ca Cl_2.6H2O, 40 kg H_2O, 40 KG Glycol) are used for experimental purpose. From the tests performed, the fabricated system was analysed and the time required for complete freezing of different PCM’s during charging and time required to achieve given temperature in the cooling cabin was noted down. Cooling effect of different PCM s are calculataed from the obtained data. The interdependence of temperature profiles and cooling effects of the various mass flow rate of air was evident from the graphs obtained and the related factor was also comprehensively studied to arrive at a conclusion.

3.1 Power consumption in kw-hr for complete freezing of different PCM's during charging.

3.1.1 Using calcium chloride as PCM.

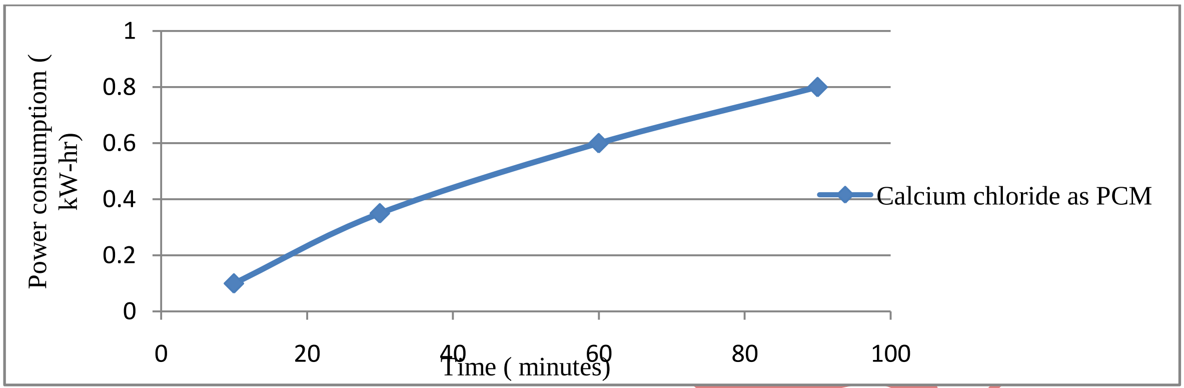

Fig 3.1 Power consumption v/s time for Calcium chloride

3.1.2 Using Water as PCM

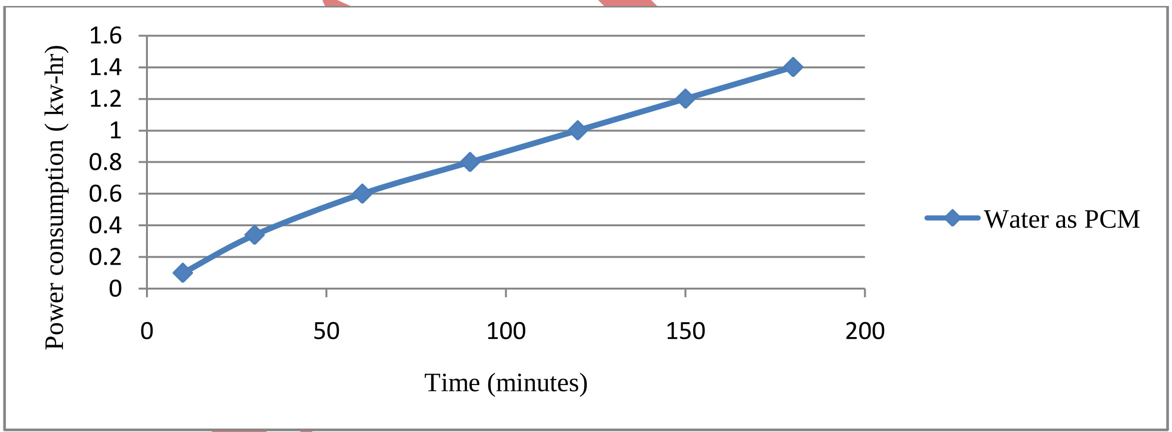

Fig 3.2 Power consumption V/S Time For Water

3.1.3 Using Ethylene glycol as PCM

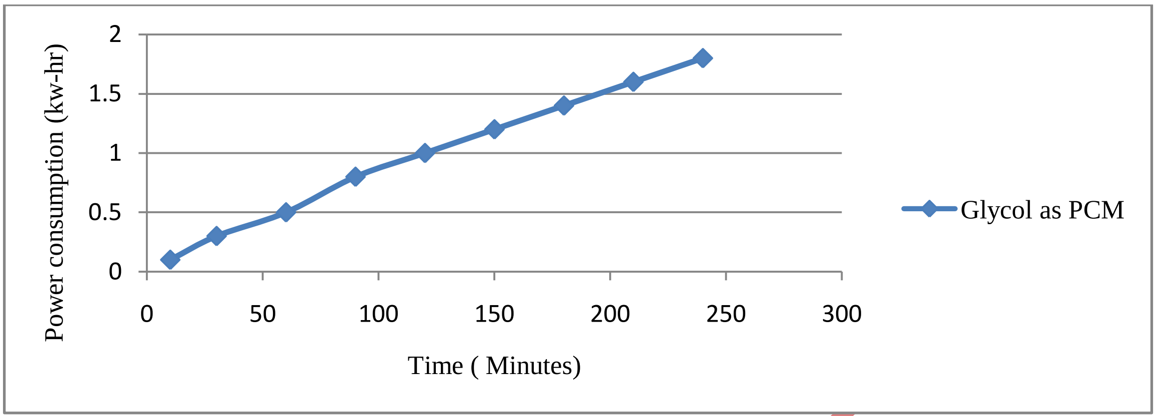

Fig 3.3 Powerconsumption v/s time for Ethylene glycol.

The power consumption in kW-hr and time for complete freezing of different PCM 's(40 kg) are presented in the above figures .It is found that power required for complete freezing of glycol is 1.8 unts (Kw –hr), For water it is 1.4 unts and for calcium chloride it is 0.8 units. Because the freezing point of these PCM 's are different. Time required for complete freezing of different PCM's are also shown in the graph.

3.2 Temperature and cooling effect variations during discharging.

3.2.1 Calcium chloride as PCM and glycol as coolant

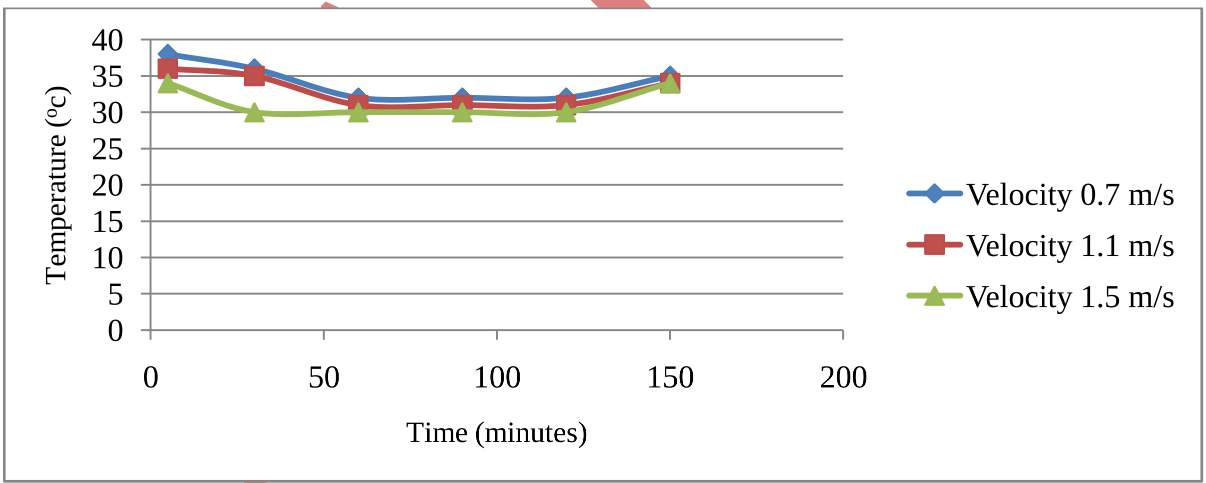

Fig 3.4 Temperature v/s time at different velocities

Fig 3.4 illustrates the variation of outlet and inlet air temperature in the cooling system versus time at different air velocities. It is found that the outlet air temperature in the cooling system is stable between 30 and 32^{0}C during ice latent heat discharging period from 25 to 130 min, and increases rapidly from 30 to 34 ^{as} during a sensible heat discharging period from 130 to 180 minutes .It was found in the experiment that, the minimum time required for attaining 30 ^{0}c in the cooling cabin when the mass flow rate is high. For a given mass flow rate, initially temperature decreases and after some time it will become constant and then decreases.

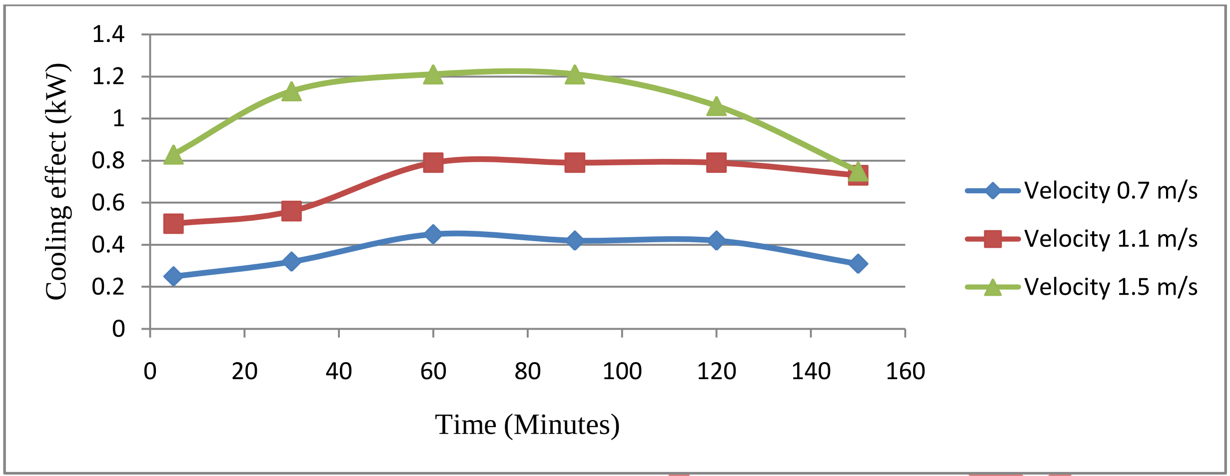

Fig 3.5 Cooling effect v/s Time

The cool discharge rate in the cooling system during the discharging period is presented in Fig.3.5. It is seen that the cooling effect is initially increasing and become stable during latent heat discharging period. During the sensible heat discharging time, the cooling effect is gradually decreasing. It is also seen that cooling effect at different velocities are different, i.e. Cooling effect is maximum at high velocities. From the graph it is clear that the discharging cycle is stably working in b/w 20 to 130 mints.

3.2.2. Using water and ethylene glycol

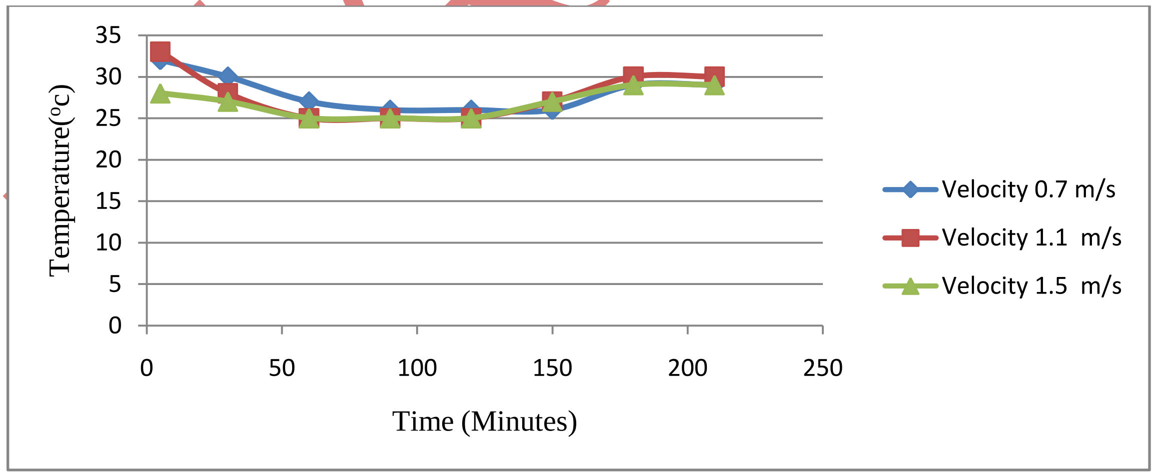

Fig 3.6 Temperature v/s time at different velocities

Fig 3.8 illustrates the variation of outlet and inlet air temperature in the cooling system versus time at different air velocities. It was found that the outlet air temperature in the cooling system is stable between 25 and 28 ^{o}C during the latent heat discharging period (0 to 150 min), and increases rapidly from 28 to 30as during sensible heat discharging period (150 to 210 min). It was found in the experiment that, the minimum time required for attaining 25°c in the cooling cabin was obtained when the mass flow rate is maximized. For a given mass flow rate, initially temperature decreases and after some time it will become constant and then again it decreases.

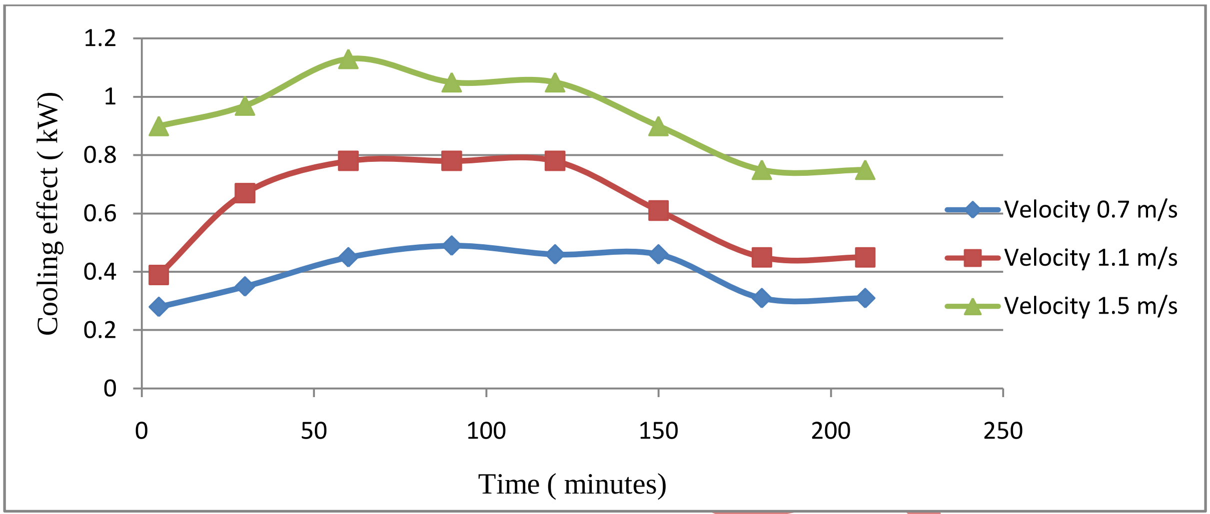

Fig 3.7 Cooling Effect V/S Time:

The discharge rate in the cooling system during the discharging period is presented in Fig 3.9. It is seen that the cooling effect initially increases and becomes stable during latent heat discharging period. During the sensible heat discharging time, the cooling effect gradually decreases as time progresses. It is also seen that cooling effect at different velocities were different, i.e. Cooling effect is maximum at a velocity of 1.5 m/s. From the graph it was clear that the discharging cycle stably works in between 20 to 180 minutes. From the graph it is clear that cooling effect and discharging time of water is higher than calcium chloride.

3.2.3 Glycol water mixture as PCM and glycoal as coolant.

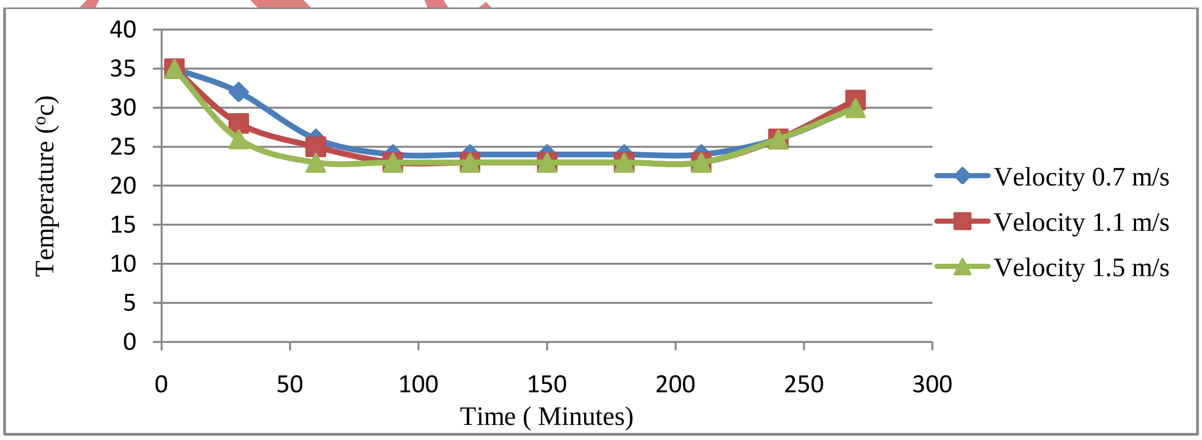

Fig .3.8.Temperature V/S Time at Different Velocities.

Fig 3.8 illustrates the variation of outlet and inlet air temperature in the cooling system versus time at different air velocities. It is found that the outlet water temperature in the cool storage tank is stable between 23 and 26 ^{o}C during ice latent heat discharging period from 10 to 210 min, and increases rapidly from 26 to 30 ^{o}C during glycol sensible heat discharging period from 210 to 280 min. It was found in the experiment that, the minimum time required for attaining 29^{o}c in the cooling cabin when the mass flow rate is high. For a given mass flow rate, initially temperature decreases and after some time it will become constant and then decreases. From the graph it is clear that discharging time of the cooling system is high , if glycol is used as PCM .That is cooling effect and discharing time of glycol is more than other PCMs.

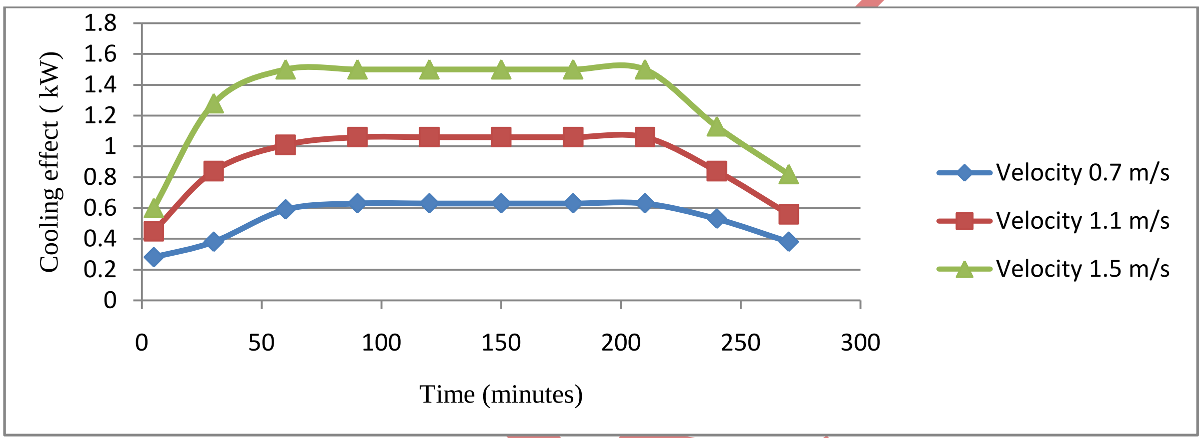

Fig 3.9 Cooling effect v/s time at different velocities

The cool discharge rate in the cooling system during the discharging period is presented in Fig. 3.9. It is seen that the cooling effect is initially increasing and become stable during latent heat discharging period. During the sensible heat discharging time, the cooling effect is gradually decreasing. It is also seen that cooling effect at different velocities are different, i.e. Cooling effect is maximum at high velocities. From the graph it is clear that the discharging cycle is stably working in b/w 20 to 250 minutes. From the graph it is clear that cooling effect and discharing time of glycol is more than other PCMs

3.3 Comparison of cooling effect & power consumption of conventional system and proposed energy storage system.

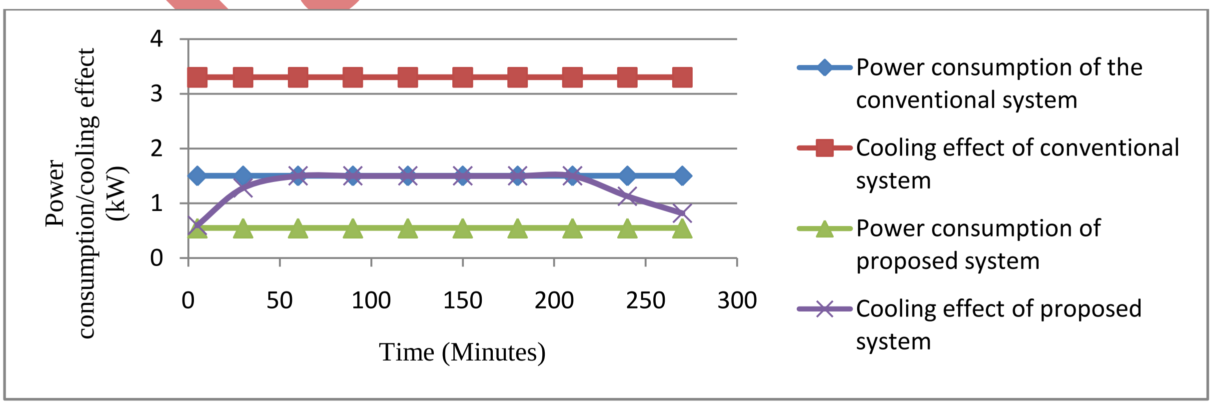

Fig 3.10 Cooling Effect V/S Time

Compared with the conventional system, cooling effect of the present energy storage system is comparatively less. But the energy consumption of conventional system is high. The cooling effect of the conventional system is constant from beginning from the end. Here, in the initial stage cooling effect less and increases and remains constant. After two and half hours cooling affects decreases rapidly.

3.4 Comparison of Power Consumption During Charging And Discharging

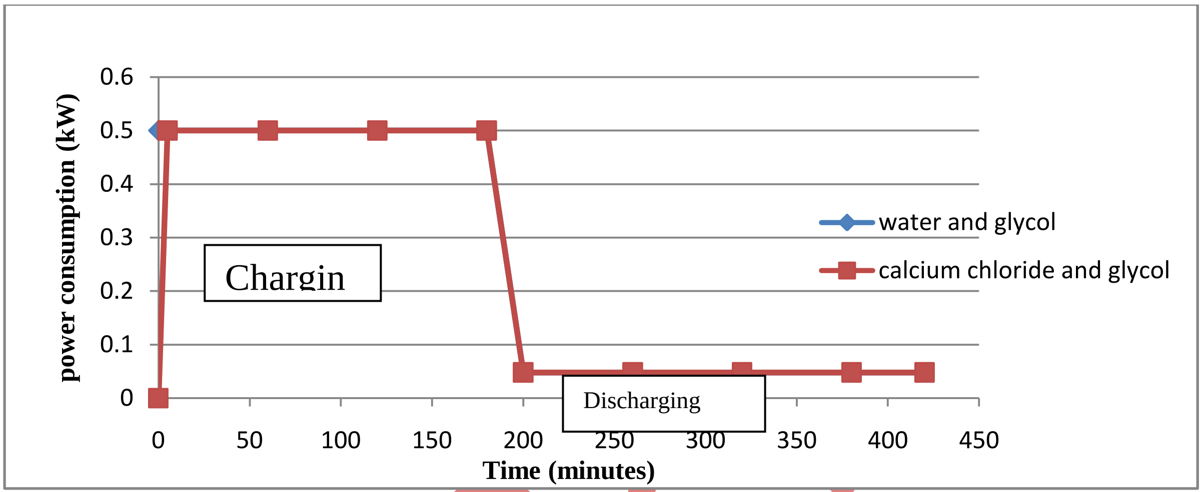

Fig 3.11 Power Consumption V/S Time

Fig shows power consumption v/s time for different PCM'S during charging and discharging. Maximum power consumption occurs during charging .After charging compressor is switched off and cooling system is started. This results in a drastic reduction in power consumption, as the pump and fan are the only power consuming devices. Power consumption during charging and discharging is constant for all the selected combinations.

IV.CONCLUSION

The study investigated the effects of various design factors for the optimal usage of an energy storage system that lowers operating costs while providing adequate occupant comfort. Water ,Ethylene glycol and calcium chloride were used as the Phase Change Materials along with ethyl alcohol and glycol as coolants in the proposed system. Analytical study of the system to measure its effectiveness based on the cooling effect and temperature variation was done. The system was fabricated based on the design and comparative study was performed keeping in mind the factors like consistency of performance, suitability and availability of working fluids and PCM's.

Thermal energy storage by using the phase change materials like calcium chloride, water and ethylene glycol is an efficient method to be used in cooling purposes. From the experimental results it is clear that cooling effect and discharging time of glycol is more than other PCMs, also it has a high latent heat of fusion The melting temperature of calcium chloride is between 28 and 30^{0}C, also it has a high latent heat of fusion, and above all calcium chloride has good physical properties such as large thermal conductivity, high density, stability. Power required for complete freezing of calcium chloride is very less than other PCM s. All these properties make it as an another suitable phase change material to be employed in a thermal energy storage system. Thermal energy storage system when coupled with a conventional air conditioning system is a yield better energy savings.

The experimental results shows cooling effect and discharging time of water is in between calcium chloride and ethylene glycol, also water has high latent heat of fusion.Compaird to others water is a cheap phase change material. The experimental results showed that the energy storage cooling system can steadily work during the charging and discharging period. The storage capacity of given PCM's are very high, as it maintains the required temperature for a longer period. Also Power consumption of the system is less as compared to conventional systems. By using this system more than 60% peak time energy consumption can be reduced. Experimental analysis also shows that $CaCl_2.6H_2O$ (calcium chloride hexahydrate) is best suitable for climatic conditions of Nagpur city, as its melting temperature is equal to the comfort temperature of the hot day.

Experimental analysis of water,ethylene glycol and calcium chloride hexahydrate based thermal energy storage for passive building cooling based on the concept of free or night cooling, have been carried out to study the energy cost saving by this system as compared to split A/C of same capacity with outdoor unit. Results show that it is feasible and advantageous to use this system for day working office rooms as it shows nearly 50% of energy saving as compare to split A/C.

This system can be very useful in the load shading affected areas of rural India where charging of thermal energy storage tank can be done when electricity is available and same stored energy can be later used when electricity is not available, i.e. This system can be used to balance the power mismatch..

Although it has the above mentioned advantages this system cannot easily use as the high cost and required quantity of PCM and also PCM material is not easily available in India. Also the COP Obtained is less as compared to existing systems. Also cooling by ac is not possible instantly as its effect depends on a state of PCM.

REFERENCES

[1] Dr.Ghalib.Y.Kahwaji,"*Application of Thermal Energy Storage Systems to Public Worship Buildings*," Al-Rafidain engineering, Vol. 14, no. 3, 2006.

[2] GuiyinFang, XuLiu, ShuangmaoWu, "*Experimental investigation on performance of ice storage air conditioning system with separate heat pipe*," Experimental Thermal and Fluid Science 33 (2009), pp. 1149–1155.

[3] Syed Mahmood Hasnain, Naif Mohammed Alabbadi, "*Need for thermal storage air conditioning in Saudi Arabia*," Applied Energy 65 (2000), pp. 153-164.

[4] A.ShanmugaSundaram, R.V.Seeniraja, R.Velraj, "*An experimental investigation on a passive cooling system comprising a phase change material and two phase closed thermo syphon for telecom shelters in tropical and desert regions,*" Energy and Buildings 42 (2010), pp. 1726–1735.

[5] GregorP.Henze, MuncefKrarti, Michal. J. Brademuehl, "*Guidelines for impro- ved performance of ice storage systems*,"Energy and Buildings 35 (2003), pp. 111-127.

[6] B.Rismanchia,R.Saidura, H.H.Masjuki, T.M.I.Mahlia,''*Thermodynamic evaluation of utilizing different ice thermal energy storage systems for cooling application in office buildings in Malaysia*," Energy and Buildings 53 (2012), pp. 117–126.

[7] V.V.Tyagi, D.Buddhi, Richa Kothari, S.K. Tyagi, "*Phase change material (PCM) based thermal management system for cool energy storage application in building: An experimental study*," Energy and Buildings 51 (2012), pp. 248–254.

[8] K.H.Yang,T.C.Yeh, "Renovation of an ice storage AC system in an aquarium for energy conservation," Building and Environment 42 (2007), pp. 1851–1861.

[9] FakehaSehar, SaifurRahman, Manisa Pipattanasomporn, *"Impacts of ice storage on electrical energy consumptions in office buildings,"* Energy and Buildings 51 (2012), pp. 255–262.

[10] Torsten Koller, Klaus Spindler, Hans Muller Steinhagen, "*Experimental and theoretical investigations of solidification and melting of ice for the design and operation of an ice store*," International journal of refrigeration 35 (2012), pp. 1253-1265.