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EXPERIMENTAL INVESTIGATION OF THERMAL ENERGY STORAGE BASED DUAL MODE AIR CONDITIONING SYSTEM

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ABSTRACT *- Electrical energy consumption varies significantly during the day and night according to the demand by industrial, commercial and residential activities, especially in extremely hot and cold climate countries where the major part of the variation is due to domestic space heating and air conditioning. Such variation leads to a differential pricing system for peak and off peak periods of energy use if some of the peak load could be shifted to the off peak load period, which can be achieved by thermal storage of heat or coolness. Phase change materials (PCM) take advantage of latent heat that can be stored or released from a material over a narrow temperature range. PCM possesses the ability to change their state with a certain temperature range. These materials absorb energy during the heating .process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling processrejection of the absorption cooling. Recently, researchers studied the heat transfer enhancement of the thermal energy storage with PCMs because most phase change materials have low thermal conductivity, which causes a long time for charging and discharging process. It is expected that the design of latent heat thermal energy storage will reduce the cost and the volume of air conditioning systems and networks*

I. Introduction

The peak demand for electricity during hot summer is increasing year by year and the daytime load has become double that of nighttime .also electrical energy consumption varies significantly during the day and night, especially in extremely cold and hot climate countries where the major part of the variation is due to domestic space heating and air conditioning. Such variation leads to an off peak period, usually after midnight until early morning. Accordingly, power stations have to be designed for capacities sufficient to meet the peak load. Otherwise, very efficient power distribution would be required. Better power generation management can be achieved if some of the peak load could be shifted to the off peak load period, which can be achieved by thermal storage of heat or coolness. Hence, the successful application of load shifting and solar energy depends to a large extent on the method of energy storage used. The main reason for this is air conditioning of commercial buildings. Therefore one way to reduce peak demand would be to use electricity supplied at night to reduce daytime air conditioner load. This would not only reduce the cost to consumers by allowing them to use electricity at cheaper night rates but would also avoid the need for capital investment in new electricity generating plants

This paper summarizes the investigation and analysis of thermal energy storage systems incorporating PCMs for use in building applications the application of PCMs In this paper the selection of materials and the methods used to contain them are discussed

A. Thermal energy storage

Thermal energy storage can be stored as a change in internalenergy of a material as sensible heat, latent heat and Thermo-chemical or combination of these.

a. Sensible heat storage

Sensible heat storage is by far themost common thermal energystorage; heat that is transferredto the storage medium leads to atemperature increase. Sensibleheat storage systems utilize theheat capacity and the changein temperature of the materialduring the process of chargingand discharging. The amount ofstored heat depends on the specific heat of the medium, the temperaturechange, and the amountof storage material 6. Specifically,the ratio of stored heat ΔQ to thetemperature ΔT is the heat capacityof the storage medium and it is expressed as

$$Q = \int_{Ti}^{Tf} mC_p dT = mC_p(T_f - T_i)$$

Equation shows thefunction between temperatureand sensible heat stored by thematerial. Often the heat capacityis given with respect to theamount of material, the volume,or the mass and is called molar, volumetric or mass specific heatcapacity, respectively. In order tobe effective as a thermal mass,a material must have a highheat capacity, a moderate conductance, a moderate density,and a high emissivity. Sensibleheat storage is often used withsolid materials, like stone, brick or concrete, or with liquids likewater, as storage materials.

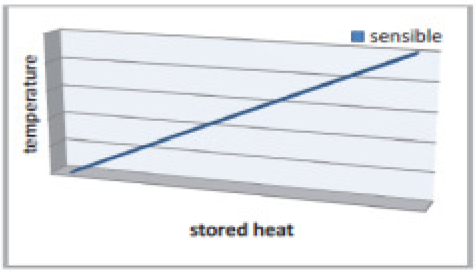


Fig 1:Heat stored as sensible heat leads to a temperature increase when heat is stored

Among common building materials,wood does not make a goodthermal mass because it not onlyhas a low heat storage potential,but is also not very conductive.Therefore, heat is not conductedreadily to the material's interiorto be stored for later use, but isrejected prematurely, as surfacetemperature rises, by radiationto cooler objects 4. Steel, whilehaving a seemingly high potentialfor heat storage, has twodrawbacks—its low emissivityindicates that a large majority ofthe incident radiation is reflected,rather than absorbed and stored,and its high conductivity signalsan ability to quickly transfer heatstored in the material's core tothe surface for release to theenvironment, thus shorteningthe storage cycle to minutesrather than the hours needed for diurnal thermal tempering Glass also seems to have a high potential for heat storage, but itis relatively transparent to near infrared radiation and reflectiveof far infrared radiation. Addingpigments to glass, especially blueand green, increases its ability toabsorb radiation, which can becomea thermal problem duringthe cooling season4. In the case ofboth steel and glass, the thicknessrequired in order to act effectivelyas diurnal thermal massis so large, heavy, and costly that it is not practical. Concrete andother masonry products are ideal,having a high capacity for heatstorage, moderate conductancethat allows heat to be transferreddeep into the material for storage,high emissivity to allowabsorption of more radiation thanthat which is reflected

When sized properly, concrete is effectivein managing diurnal energyflow . Conveniently structuralconcrete and thermal mass sharecommon dimensions, so there isno wasted mass when building astructure. Water is also effectiveas a thermal mass in that it has high potential for heat storageand it can be effective in a diurnalthermal management scheme.Water use is more problematicalin that, unlike concrete, itserves no structural purpose inconstruction, but when stored inclear or translucent containers can provide light and/or viewsthrough the normally opaquethermal mass.. Gases have verylow volumetric heat capacityand are therefore not used forsensible heat or cold storage.Sometimes in order to effectivelyuse the material thermal mass, asignificant material thickness isrequired. .

b. Latent heat storage

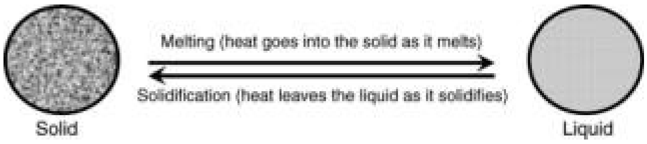
Latent Heat Storage (LHS) isbased on the heat absorption orrelease when a storage material undergoes a phase change fromsolid to liquid or liquid to gas orvice–versa.If heat is stored in latent form,the energy stored is largely associated with phase change inthe storage medium. Latentheat storage provides a highenergy storage density and hasthe capacity to store heat aslatent heat of fusion at a constanttemperature corresponding tothe phase transition temperatureof the phase change materials. Latent heat storage can be accomplished through solid-liquid,liquid-gas, solid-gas and solid-solid phase transformations, butthe only two of practical interestare the solid-liquid and solid-solid. Solid-gas and liquid-gastransition have a higher latentheat of fusion but their largevolume changes on phase transition are associated with containment problems and rule out theirpotential utility in thermal storage system[9]. The phase changesolid-liquid by melting and solidification can store large amountsof energy, if suitable material isselected. Materials with a solid-liquid phase change, which aresuitable for heat or cold storage,are commonly referred to aslatent heat storage materials orsimply phase change materials.

The liquid-vapor phase changeby evaporation and condensationusually has a large phase changeenthalpy; however the processof evaporation strongly dependson some boundary conditions.

Latent heat storage is more attractive than sensible heat storage because of its high storage density with smaller temperatureswing. However, many practical problems are encounterwith latent heat storage due to thermo-physical properties underextended cycles, phase separation, sub-cooling, incongruentmelting, volume change and highcost. Phase separation occurs ina substance that consists of twoor more components and insteadOf keeping the same homoge-neous composition while melting,it separates into different phasesone for each component. Sub-cooling or super-cooling occurswhen a material does not solidify immediately upon cooling below the melting point, but starts crystallization after a temperaturewell below the melting point isreached..

II. Phase Change Processes

Latent heat storage is one of the most efficient way of storing thermal energy. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with a smaller temperature difference between storing and releasing heat [10]. Every material absorbs heat during a heating process while its temperature is rising constantly. The heat stored in the material is released into the environment through a reverse cooling process. During the cooling process, the material temperature decreases continuously. Comparing the heat absorption during the melting process of a phase change material (PCM) with those in normal materials, much higher amount of heat is absorbed if a PCM melts.



A paraffin PCM, for an example, absorbs approximately 200 kJ/kg of heat if it undergoes a melting process High amount of heat absorbed by the paraffin in the melting process is released into the surrounding area in a cooling process starts at the PCM's crystallization temperature. After comparing the heat storage capacities of textiles and PCM, it is obvious that by applying paraffin-PCM to textiles their heat storage capacities can substantially enhanced [6].During the complete melting process, the temperature of the PCM as well as its surrounding area remains nearly constant. The same is true for the crystallization process during the entire crystallization process the temperature of the PCM does not change significantly either. Phase change process of PCM from solid to liquid and vice versa is schematically shown in FigThe large heat transfer during the melting process as well as the crystallization process without significant temperature change makes PCM interesting as a source of heat storage material in practical applications. When temperature increases, the PCM microcapsules absorbed heat and storing this energy in the liquefied phase change materials. When the temperature falls, the PCM microcapsules release the this stored heat energy and consequently PCM solidify.

A. Phase Change Materials

Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity. They should have a melting temperature lying in the practical range of operation, melt congruently with minimum sub-cooling and be chemically stable, low in cost, nontoxic and non-corrosive According to the literature PCMs can be classified into organic, inorganic, and eutectics. The melting temperature of the PCM to be used as thermal storage energy must match the operation range of the application the PCMs should first be selected based on their melting temperature. Materials that melt below 15 C are used for storing coolness in air conditioning applications, while materials that melt above 90 C are used for absorption refrigeration. All other materials that melt between these two temperatures can be applied in solar heating and for heat load leveling applications

a. Organic PCM

Organic PCMs have a number of characteristics which render them useful for latent heat storage in certain building elements. They are more chemically stable than inorganic substances, they melt congruently and super-cooling does not pose as a significant problem. Moreover, they have been found to be compatible with and suitable for absorption into various building materials, as will be discussed in more detail later. Although the initial cost of organic PCMs is higher than that of the inorganic type, the installed cost is competitive.

b. Inorganic PCM

Development of latent heat storage materials used inorganic PCMs. These materials are salt hydrates, including Glauber's salt (sodium sulphatedecahydrate), which was studied extensively in the early stages of research into PCMs. The phase change properties of these materials are shown in Table 1. These PCMs have some attractive properties including high latent heat values, they are not flammable and their high water content means that they are inexpensive and readily available. However, their unsuitable characteristics have led to the investigation of organic PCMs for this purpose. These include corrosiveness, instability, improper re-solidification, and a tendency to supercool. As they require containment, they have been deemed

III. Classification of PCM

The melting temperature and the melting enthalpy of phase change materials are the two most important They are more chemically stable than inorganic substances, they melt congruently and super-cooling does not pose as a significant problem. Moreover, they have been found to be compatible with and suitable for absorption into various building materials. Although the initial cost of organic PCMs is higher than that of the inorganic type, the installed cost is competitive

A. Paraffins

Paraffin is the technical name for an alcane, but it is especially used for linear alcanes with thegeneral formula CnH2n+2. Little information is given for their crystal structure. The normal paraffinns of type CnH2n+2 are a family of saturated hydrocarbons with very similar properties. Paraffi ns between C5 and C15 are liquids, and the rest are waxy solids9. Pure alcanes are rather expensive. Commercial paraffin is obtained from petroleum distillation and it is a combination of different hydrocarbons. These mixtures show a lower melting range and a lower heat of fusion than the pure Alcanes.

B. Fatty acids

Fatty acids are characterizedby the chemical formulaCH3(CH2)2nCOOH. Their meltingenthalpy is similar to that of paraffin ns and their melting temperatureincreases with the lengthof the molecule. Their characteristicsare generally similar toparaffi ns. A difference to paraffin ns can be expected in the compatibilityof fatty acids to metals,due to their acid character. Fattyacids are stable upon cycling;because they consist of only onecomponent there cannot be phaseseparation. Like paraffins, fatty acids also show little or no super-coolingand have a low thermalconductivity. Their advantage ofsharper phase transformationsis offset by the disadvantage ofbeing about two or three timesthe cost of paraffins. They arealso mildly corrosive. Differentfatty acids can be mixed to designphase change materials with differentmelting temperature thanpure fatty acids; the combinationof fatty acids to obtain melting
temperatures ranging from 20–30°C with an accuracy of ± 0.5 °Ccan be promisin. This wouldallow a designer to select theoptimum operating temperatureto obtain the maximum performanceof a heat storage system .

C. Sugar Alcohols

Sugar alcohols are a hydrogenatedform of a carbohydrate.The general chemical structure isHOCH2[CH(OH)]nCH2OH. Differentforms are obtained depending onthe orientation of the OH groups.Sugar alcohols are a rather newmaterial; therefore little general information is available.They have melting temperaturesin the 90^0C to 200^0C range and their specific melting enthalpiesare comparatively high in mostcases7. Additionally, sugar alcoholshave high density which resultsto very high volume specificmelting enthalpies. In contrastto many other organic materials sugar alcohols show some supercooling

D. Non-paraffin's

This is the largest category of candidate materials for latentheat storage. There is a number of esters, fatty acids, alcohols, and glycols suitable for energy storage that are further subgroups of fatty acids and other non-paraffin organics. The non paraffin organics are the most numerous of the phase change materials, with highly varied properties. Each of these materials will have its own properties,unlike the paraffins, which have very similar properties. These materials are flammable andshould not be exposed to excessively high temperature, flamesor oxidizing agents

IV. Objective of Research work

Find out the optimum Flow Rate and mass Ratio of Glycol and water for maximum COP of Air conditioning system also The main objective behind this paper is to design phase change material based thermal energy storage for active building cooling as Electrical costs peak during the day when demand is at its highest and are significantly less during evening hours when demand decreases. TES is one of the most preferred demand side management technologies for shifting cooling electrical demand from peak daytime hours to off peak night hours.

V. Experimentation & Methodology

Experimental setup can be divided in two parts as follows.

1) Glycol based Thermal Energy Storagetank . 2) Air conditioning duct

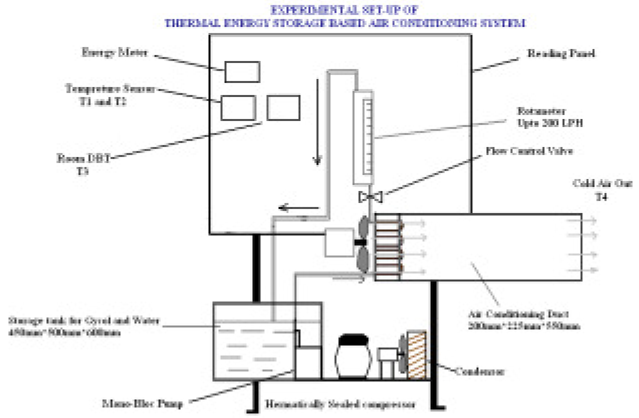


Fig. 2 Experimental setup

Proposed experimental set up works on the principal of free/night cooling and active building cooling with the help of force draft cooling by cooling tower during mid-day period.

A. Glycol solution as Thermal Energy Storage material

Glycol solution as thermal energy storage materialused in the experimentation, initially solution of measured quantity is mixed with water directly inside thermal energy storage tank. for the same mass ratio.mixed solution is allow to keep for the experimentation and readings. First The ratio for mixture of water and glycol is same means 1:1 initially 5 liters of glycol and 5 liters of water . As the experimentation is carried out more 5 liters of water is added to the existing solution to make ratio 1:2

B. Storage tank

Storage tank made of galvanized sheet with insulation for storing liquid Glycol and water insulation is provided as the temperature of the solution is falls below the freezing point of water so to prevent heat transfer to environment ½ inch of wool layer is used .storage tank has a dimensions of width, height and length of 450mm x 500mm x 600mm respectively. This rectangular duct is made of sheet metal (MS) on three sides. The tank has a capacity of about storing capacity of 80 liters.

C. Evaporator section made of Copper tubes

storing the thermal energy during the night or during charging process the temperature of the solution is falls below freezing point of water . and during discharging the low temperature solution is allow to pass through this copper tubes to effect the cold energy inside the room.tubes having a cross section of 9.52mm inside tube diameter

D. Discharge duct with insulation

Discharge duct it is made up of Mild Steel sheet material a square in cross section .setup consists of a discharge duct of width, height and length of 250mm x 250mm x 900mm respectively. after storing the thermal energy during the night or during charging process the temperature of the solution is falls below freezing point of water . and during discharging the cold air is allow to pass to room through this duct

E. Fan unit

Fan unit is provided before the air conditioning duct for maintaining the constant discharge of air over the copper section through the discharge duct

F. Monobloc pump

Monobloc pump for maintaining discharge of solution through evaporator coils section of air conditioning system capacity of the pump is to discharge 500 liters of water per hour.

G. Rota meter

Rota meterfor measuring discharge of the solution through the evaporator copper coil section. The capacity of the Rota meter is to measure the flow of liquid up to 200 liters per hour.

Experimentation started with the concept of free night cooling. During night temperature of the atmosphere is falls so that time charging of solution is done for that purpose conventional vapor compression system is used

.Water and glycol solution in same quantity or same mass ration is taken inside in thermal energy storage tank. Start the compressor refrigerant R134a started flowing through the system 1 tonne capacity of hermetically sealed compressor is used forced draught fan is also used in the system for cooling of condenser instead of natural cooling.

After some time temperature of the solution is falls to a specified temperature take the temperature reading of solution on the reading panel by the use of digital temperature indicator

Now the charging mode is over cold energy is stored inside the solution during the day time switch off the conventional vapor compression refrigeration system.

Start ON the monobloc pump or water pump hence solution starts flowing through the copper section and also through the rot meter . flow of the solution can be maintained in liters per hour by operating the valve of the rot meter. When the solution passes through the copper tubes switch on the air conditioning duct fan. Atmospheric air start flowing and comes in contact with the copper coils and temperature of this air is falls to a desired level .

Cool air is now blown inside the room . Dry Bulb Temperature and Wet Bulb Temperature of the discharge air is measured with the help of hygrometer

Selection of material

Ethylene Glycol based water solutions are common in heat-transfer applications where the temperature in the heat transfer fluid can be below *32°F (0°C)*. Glycol is also commonly used in heating applications that temporarily may not be operated (cold) in surroundings with freezing conditions

Data Collection or Observation

To calculate the coefficient of performance (COP).Temperature at different point and energy meter reading are necessary to record during experimentation.

Cooling effect at Variable mass ratios of glycol and water
Variable inlet water flow through the evaporator of duct

Inlet water flow (100 LPH) through the evaporator of duct for Mass ratio(1:3)

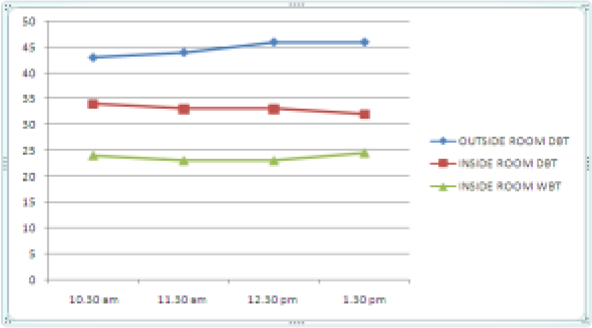
Cooling Effect Analysis (Flow rate 100 LPH)											
Sr. no.	Flow rate (Lt/min)	Time	water inlet Temp ^{0}C **(T1)**	Water outlet Temp. ^{0}C **(T2)**	outside Dry bulb Temp ^{0}C	outside Wet bulb Temp ^{0}C	Enthalpy h_o kJ/kg	Room dry bulb temp.^{0}C**(T3)**	Room wet bulb tem ^{0}C**(T4)**	Enthalpy h_i kJ/kg	Power input KW-h
1	**100**	10.30 am	-5	2	43	22	114	34	24	74	0.25
2	**100**	11.30 am	2	11	44	22	116	33	23	71	0.25
3	**100**	12.30 pm	12	15	46	21	119	33	23	71	0.25
4	**100**	1.30 pm	21	24	46	21	119	32	24.5	68	0.25

Table no 1 :- DBT and WBT of Room v/s Time

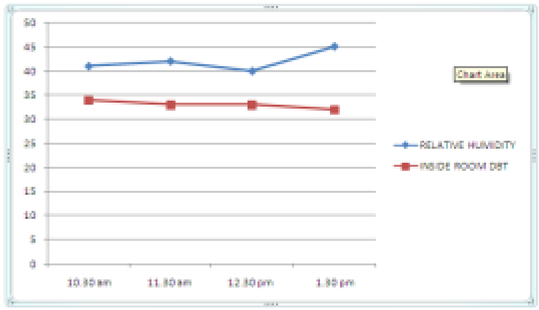
Effect of Relative humidity (%) in inside room for 100 LPH

S.No	Time	DBT of Room(^{0}C)	WBT of Room(^{0}C)	Relative Humidity (%)
1	10.30 am	34	24	41
2	11.30 am	33	23	42
3	12.30 pm	33	23	40
4	1.30 pm	32	24.5	45

Graphs and comparisons
1)Time V/S Temperature Graph for mass ratio(1:3)& inlet water flow 100 LPH
2) Time V/S Humidity Graph for mass ratio(1:3) & inlet water flow 100 LPH



Time v/s Tempreture for mass ratio 1:3 and 100 LPH



Time v/s relative humidity at mass ratio 1:3 and 100 LPH

Calculations

- mass ratio 1:3 and inlet water flow rate of 50 LPH

COP of the system can be calculate as
COP = M_a x ($h_o - h_i$) /W
COP = ma * (Ho- Hi) / p
COP = 0.0679*(110-68)/(1.25+0.23)
COP = 1.93

- mass ratio 1:3 and inlet water flow rate of 75 LPH

COP = ma * (Ho- Hi) / p
COP = 0.0679*(113-68)/(1.25+0.25)
COP= 2.037

- For mass ratio1:3 and inlet water flow rate of 100 LPH

COP = ma x (Ho- Hi) / P
COP = 0.0679* (119-68)/(1.25+0.23)
COP= 2.33

VI. Results And Discussions

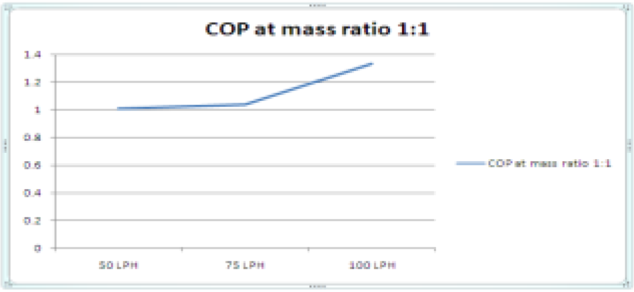
The experiments were carried out for both charging and discharging mode . The experimentation is divided in following cases.
a) Case I: for the same mass ratio(1:1) of glycol solution and water ie 5 liters of solution is mixed with the 5 liters of the water so ratio becomes same total solution becomes 10 liters
b) Case II:for the mass ratio (1:2) of glycol solution and water ie 5 liters of solution is mixed with the 10 liters of the water so ratio becomes 1:2 total solution is 15 liters.
c) Case III: for the mass ratio of glycol solution and water ie 5 liters of solution is mixed with the 15 liters of the water so ratio becomes 1:3 total solution is 20 liters
Based on the observations recorded while experimentation, following parameters are calculated.

1. Power required for charging process in all cases
2. Dry bulb temperature of the room

3. Wet bulb temperature of room
4. Relative humidity of the room
5. COP coefficient of performance of the air conditioning system at various mass ratios

The experimentation was carried out with different mass ratios of solution and water at variable flow rate various factors like DBT,WBT,Relative-Humidty and COP are calculated for all cases. Parameters were plotted for COP V/s mass ratio.
Following graphs are plotted to compare the coefficient of performance of different mass ratio.

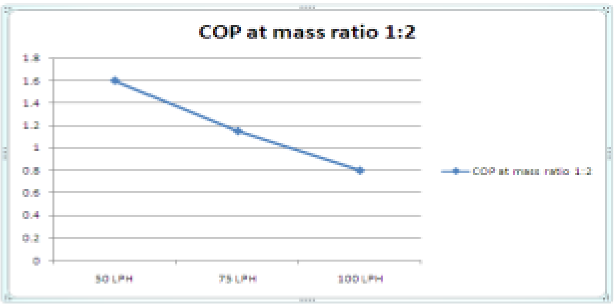
Variation of COP with Flow rate at same mass ratio (1:1)



COP v/s Flow rate of solution

It is observed that the coefficient of performance increases with increase in rate of flow of solution through rotameterincreases,from 50 liters per hour to 100 liters per hour if mass ratio is taken same (1:1)

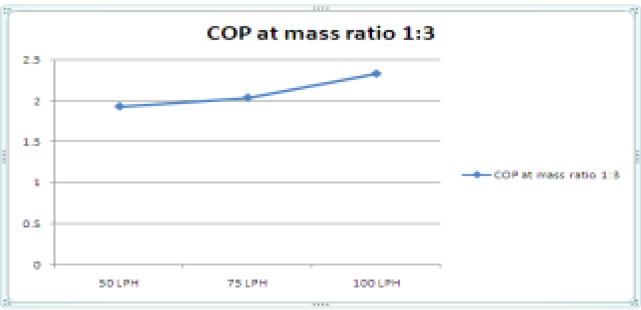
Variation of COP with Flow rate at mass ratio (1:2)



COP v/s flow rate of solution at mass ratio 1:2

It is observed that the coefficient of performance decreases with increase in rate of flow of solution through Rotameter. initially at 50 liters per hour cop is maximum but after increasing flow to 75 LPH decreases and finallyat100 liters per hour it decreases to a minimum level if mass ratio is taken as (1:2)

Variation of COP with Flow rate mass ratio (1:3)



COP v/s flow rate at mass ratio 1:3

It is observed that the coefficient of performance increase with increase in rate of flow of solution through Rotameter. initially at 50 liters per hour cop is 2 but after increasing flow to 75 LPH and finally at 100 LPH it attains a maximum level about 2.4 if mass ratio is taken as (1:3)

VII. Conclusion

1) COP of the system increases with increase in quantity of the glycol solution mixing with water.
2) COP of the system increases with increase in inlet water flow to Fan Coil Unit or copper coils .
3) Glycol solution is best suitable for climatic conditions of Nagpur city, as its melting temperature is equal to the comfort temperature of hot day.
4) Quality of air obtained by this system is much better than theobtained by dessert coolers in rural India.This system cannot easily used as the high cost and required quantity of PCM
5) COP Obtained is less as compare to existing systems.
6) Cooling by AC is not possible instantly as its effect depends on a state of PCM.
7) 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.

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