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Design and Development of Combined Direct and Indirect Evaporative Cooling System

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ABSTRACT

Cooling is an essential part of air conditioning in hot climates. The issues of global warming, the natural resources depletion, and demand for environmentally-friendly systems have led to a growth in use of natural green resources instead of conventional systems. Two methods of evaporative cooling are normally used that is direct evaporative cooling & indirect evaporative cooling. Indirect evaporative cooling can be utilized to cool the air or other fluid with wet surface heat exchangers.
This paper theoretically&experimental analyses the performance of combined direct and indirect evaporative cooling in hot and dry climate of Pune, India. Indirect cooling stage consisting of plateFin type wet surface heat exchanger followed by direct cooling evaporative consisting of paper cellulose cooling pad is considered. Based on summer weather data of Pune, most frequently occurring condition of 35°C DBT and 50 % RH is selected for the analysis. Minimum temperature of direct evaporative cooling is 26.5°c achieved. 1KW of cooling capacity is achieved with COP of system 6.5. Experimentation of air temperature, relative humidity, cooling capacity, COP changes done at different air flow.

Keywords- **Indirect Evaporative, Direct Evaporative, Cooling Capacity, Cellulose pad.**

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I. INTRODUCTION

Cooling is an essential part of air conditioning in hot climates. The issues of global warming, the natural resources depletion, and demand for environmentally-friendly systems have led to a growth in use of natural green resources instead of conventional systems. Two methods of evaporative cooling are normally used. Direct evaporative cooling (DEC) is the oldest, and the most widespread form of cooling systems. The principle of DEC is the conversion of sensible heat to latent heat. Indirect evaporative cooling can be utilized to cool the air or other fluid with wet surface heat exchangers. The surface of the cooling air passages is wetted by spray water, so that water film evaporates into the cooling air and decreases the temperature of the wetted surface. The primary air or other process fluid flows in the alternative passages and is cooled by indirect contact with the spray water film through the separating wall of the heat exchangers. Several research papers reviewed in the direction of indirect evaporative cooling, characteristic and effectiveness of indirect evaporative cooling.

Evaporative cooling is a process of heat and mass transfer based on the transformation of sensible heat into latent heat. If the process develops in ideal adiabatic conditions, the dry bulb air temperature decreases as this transformation develops, increasing its humidity [1,2].
Evaporative cooling is classified as direct evaporative cooling and indirect evaporative cooling.

A. Direct evaporative cooling system

Direct evaporative systems, water evaporates directly in the air stream, producing an adiabatic process of heat exchange in which the air dry bulb temperature decreases as its humidity increases. Thus, the amount of heat transferred from the air to the water is the same as the one employed in the evaporation of the water [3].

B. Indirect evaporative cooing system

Indirect evaporative coolers take advantage of evaporative cooling effects, but cool without raising indoor humidity and develop the indirect evaporative cooling prototype. Indirect evaporative air cooler passes the primary (product) air over the dry side of a heat/mass exchanging wall, and the secondary (working) air over its opposite wet side. The wet side absorbs heat from the dry side by evaporating water and therefore cooling the dry side, while the latent heat of vaporizing water is given to the wet side air. Under the ideal operating condition, i.e., the product air travelling in a counter-flow manner to the working air and the two airstreams having a good balance of flow rates and an infinite contact area, the product air temperature on the dry side of the sheet will reach the wet bulb temperature of the incoming working air and the temperature of the working air on the wet side of the sheet will increase from its incoming dry bulb temperature to the incoming product air dry bulb temperature and be saturated [4]. However, practical systems are far from this ideal. It has been suggested that only 50% of the incoming working air wet bulb temperature can be achieved for a typical indirect evaporative cooling system.

The indirect evaporative cooling systems can be considered as energy recovering systems if a return air stream from the room cooled is used as a secondary air stream in the process, taking advantage of either its lower temperature or humidity. It can also be used a mixed stream of outside and return air [1].

I. Literature Review and objectives

E. Velasco Gómez et al. [1] describes the phenomenon of evaporative cooling is a common process in nature, whose applications for cooling air are being used since the ancient years. In fact, it meets this objective with low energy consumption, being compared to the primary energy consumption of other alternatives for cooling, as it is simply based in the phenomenon of reducing the air temperature by evaporating water on it. Chengqin Ren et. al. [2] describes developing an analytical model for the coupled heat and mass transfer processes in indirect evaporative cooling under real operating conditions with parallel/counter flow configurations. Conventionally, one-dimensional differential equations were used to describe the heat and mass transfer processes. In modelling, values of Lewis factor and surface wet ability were not necessarily specified as unity.ShahramDelfani et al. [3] the performance of indirect evaporative cooling system (IEC) to pre-cool air for a conventional mechanical cooling system has been investigated for four cities of Iran. For this purpose, a combined experimental setup consisting of an IEC unit followed by a packaged unit air conditioner (PUA) was designed, constructed and tested. Two air simulators were designed and used to simulate indoor heating load and outdoor design conditions. The results indicate IEC can reduce cooling load up to 75% during cooling seasons. Also, 55% reduction in electrical energy consumption of PUA can be obtained. Aftab Ahmad et al. [4] investigated the performance of a 5-ton capacity indirect evaporative cooler under controlled environmental conditions (43.9°C dry-bulb temperature and 19.9% relative humidity) but for different air flow rates (631 to 2388 m3/h). The experimental results showed that the intake air energy efficiency ratio of the cooler varied from 7.1 to 55.1 depending on test conditions and air flow rate. The power consumption of indirect evaporative cooler was found to vary from 68.3 to 746 watts. Water consumption was found to vary between 0.0160 and 0.0598 m^3/h. At full fan speed, an average of 58.7% of the total water consumed by indirect evaporative cooler was evaporated.

Direct evaporative cooling systems can lower the temperature of air using the latent heat of evaporation. As a result, warm dry air is changed into cool moist air, but the energy in the air remains the same [5]. Existing direct evaporative cooling systems are 70–95% effective in terms of the incoming air's wet bulb temperature and only suitable for use in dry, hot climates, or rooms needing both cooling and humidification. Therefore increase humidity and decrease in temperature is occurs in direct evaporative cooling. Because of increase in humidity thermal comfort is not satisfy to control that parameter we use indirect evaporative cooling system. The objectives of the research are to investigate direct&indirect evaporative cooling systems. This system design and development for 1 kw output. The different variation of airflow to be considered for effective cooling system.

II. Methodology and Design Considerations

The objective of this work is to investigate the performance of direct &indirect evaporative cooling for the output temperatureof human thermal comfort [4].This system is focus on heat exchanger, material, flow direction at incoming working air wet bulb temperature can be achieved for a typical indirect evaporative cooling system. The study will be conducted using design and experimental apparatus. The schematic of indirect evaporative cooling is shown in figure Fig.1 in which ambient air is forced on Cellulose pad followed by tube and fin heat exchanger is new design consideration.

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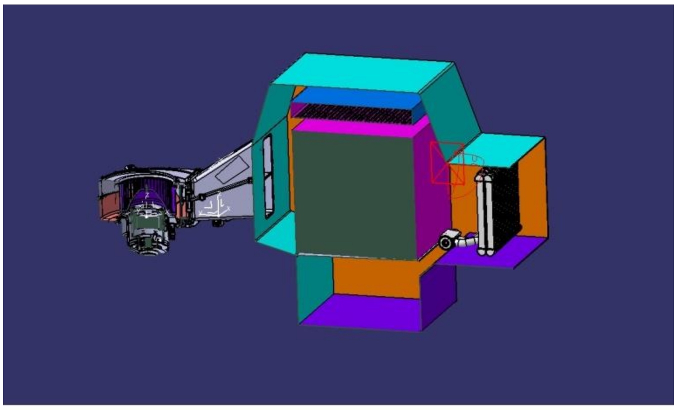

Fig.1 indirect evaporative cooling

This process is called indirect and is mainly used in those applications where no humidity addition is allowed in the supply air, as well as no risks of contamination, as no mass exchange is permitted between the two air streams.

A. *Assumptions*

The following assumptions are made in IEC analysis.

1) Surface wetting in DEC is complete.

2) Miscellaneous load such as make up water addition, pump heat gain and heat gain from ambient are neglected.

3) Heat and mass transfer coefficients are constant.

4) Temperature and enthalpy at air-water interface is represented by a constant average temperature over the entire surface.

B. *Material for Direct Evaporative cooling*

Material Selected for evaporative pads:

Cellulose pad: Sheet thickness 0.2mm

Manufacturer: M/S Munters

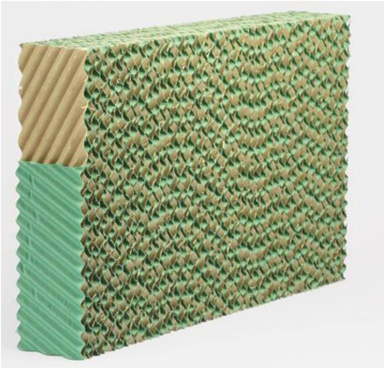

Fig. 2CELdek® 7090-15 evaporative cooling pad manufactured by Munters

CELdek® 7090-15 evaporative cooling pad is used in systems where high efficiency cooling is required & shown in fig. 2. It can be used for many different cooling purposes but is particularly suitable for cooling of livestock buildings and greenhouses. The Green stripe pad consists of specially impregnated and corrugated cellulose paper sheets with different flute angles, one steep (60 deg) and one flat (30 deg) that have been bonded together. This unique design yields a cooling pad with high evaporation efficiency while still operating with a very low pressure drop. In addition scaling is kept to a minimum and no water carryover occurs due to the fact that the water is directed to the air inlet side of the pad. This is where most of the evaporation takes place. For better efficiency of DEC, we select the 300mm thickness of pad at average velocity of 4m/s, which derives 93% efficiency of cooling.

C. *Design Considerations*

For Pune, Frequent ambient condition is DBT =35ºC and 50% RH.This is used as inlet condition for design of IEC system. The properties of air based on this condition are as below;

DBT-35ºC, RH-50% WBT-23ºCEnthalpy of intake air h_{in} =81 KJ/kg of dry air

Temperature reduction achievable in DEC is given by=

(DBT-WBT) X Efficiency of pad = (35-23)x0.93=11.96ºC

Thus achievable temperature=35-11.16=23.84ºC

Corresponding values of RH from Psychometric chart is 92% and enthalpy as 69 KJ/Kg of dry air.

So air condition before and after the evaporative cooling pad is:

Before DBT as 35ºC and WBT as 23ºC

After DBT as 23.84ºC WBT as 23ºC,

Enthalpy at the outlet of evaporating pad is h_{out}=69 KJ/kg of dry air

D. *Pad Material and geometry*

Total wetted surface area(m^2) of pad is given by,

$$Aw=Vp.As$$

Where, As=wetted surface area of pad per unit volume (m^2/m^3) = 70 m^2/m^3 for selected cellulose pad

Vp = Volume of the pad

Aw= 70 x (0.3x0.3x0.3)

=1.89 m^2

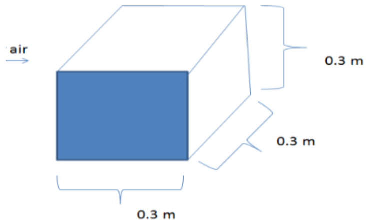

Fig. 3 Cellulose pad area

E. *Airflow requirement:*

The maximum cooling load is obtained with the equation as:

$Qc=m(h_{in}-h_{out})$ -------Qc in KW

1=m(81-69)

m=0.083kg/s

F. *Amount of Water Evaporated in system:*

Evaporation heat of water=2270 KJ/kg

Amount of water evaporated per second (M_{evap}) during cooling process is given by equation,

$Qc=2270x\ M_{evap}$

$1 = 2270x\ M_{evap}$

M_{evap} = 0.00044 kg/s

Which is equivalent to 26 ml of water per minutes, So while selecting feed water pump this additional quantity need to be considered.

To get comfortable RH value lesser, 50% of fresh ambient air & DEC output air mixture is used.

$m_1h_1+m_2h_2=m_3h_3$

Where, m_1= Ambient air

m_2=outlet of DEC air

m_3=Mixture air (m_{1+} m_2)

(0.5x81)+ (0.5x65.5) = (0.5+0.5) h_3

h_3=73.25KJ/Kgof dry air

RH=69%, T_3=28.8 ºC

III. Experimental setup and testing

To evaluate performance of DEC/IEC system in defined ambient conditions and in order to investigate effect of operational parameters, an experimental setup was designed, constructed & tested as shown in Fig. 4.

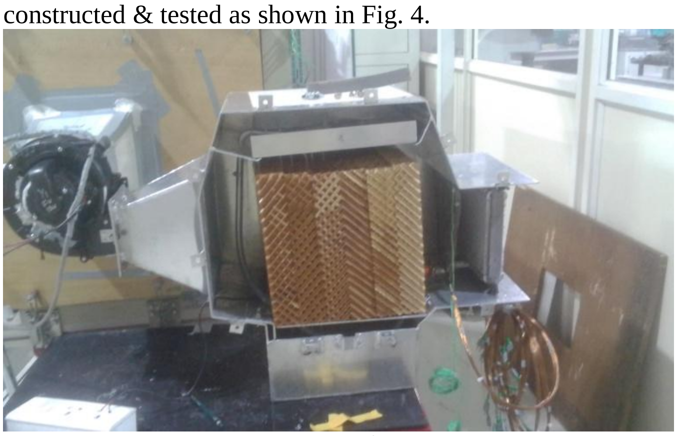

Fig. 4 Experimental Setup of DEC/IEC system

Test setup consists of IEC/DEC unit including a 300 mm thick cellulose pad as DEC unit, a heat exchanger in which water as cooling media as IEC unit, a water circulating pump. Water is distributed over Cellulose DEC pads using proper perforated plate which allows uniform and continuous water flow to wet. Specifications of this heat indirect exchanger have been presented in Table 1.

TABLE I
HEAT EXCHANGER SPECIFICATION

1	Heat Exchanger type	Tube and Fin
2	Size(mm)	210X200X40
3	Fin density(per 100mm)	75 fins
4	Effective frontal Area (mm^2)	356

Temperature and relative humidity (RH) are measured in the following positions:
– Air temperature and RH after the DEC unit
– Air temperature after the IEC unit in primary flow.
– Water temperature of DEC water tank (above DEC pad)
– Water temperature of Heat Exchanger inlet and outlet pipes.
The relative humidity was measured by the sensors in the range of 10% to 95% and the accuracy and resolution were 3% and 0.01% respectively.Also air flow, current was measured at the outlet of IEC heat exchangers.

IV. RESULT & CONCLUSIONS

Results show that the air temperature drops to 26.5ºC from 35ºC. Relative humidity at the outside of indirect heat exchanger is increased to 73.8% from 50% of ambient air.From observations,RH value is reduced by 23.8% in IEC than DEC outlet at 450m^3/hr of airflow. This is achieved with 50% of ambient air mixing at IEC heat exchanger. Study also reveals the air temperature and relative humidity are less at less air flow. The output cooling capacity is achieved is close 1KW with air flow at 350 m^3/hr.

The graph represent the mass flow rate Vs Temperature.

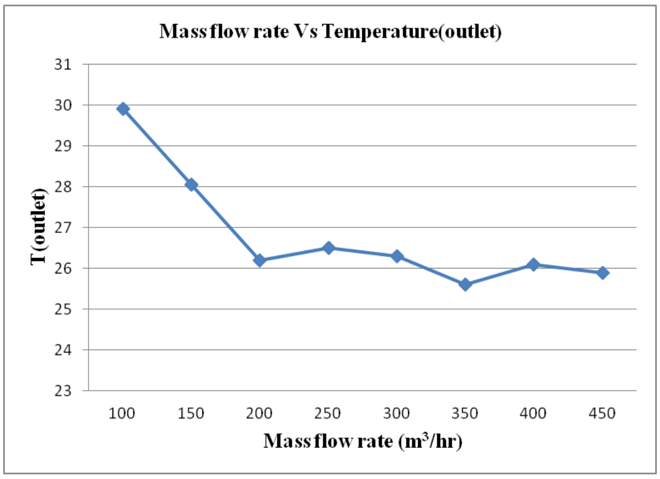

Fig.5 Mass flow rate changes with temperature outlet of IEC.

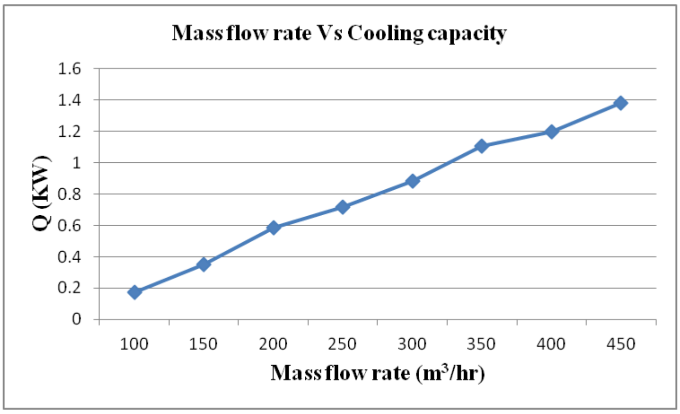

Fig. 6 Cooling capacity of IEC system

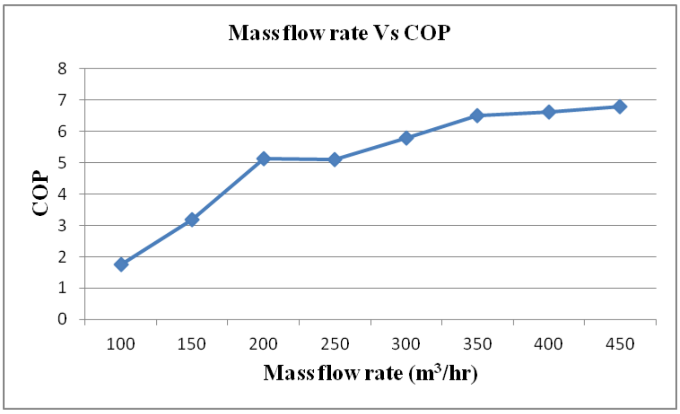

Fig. 7 COP of IEC system

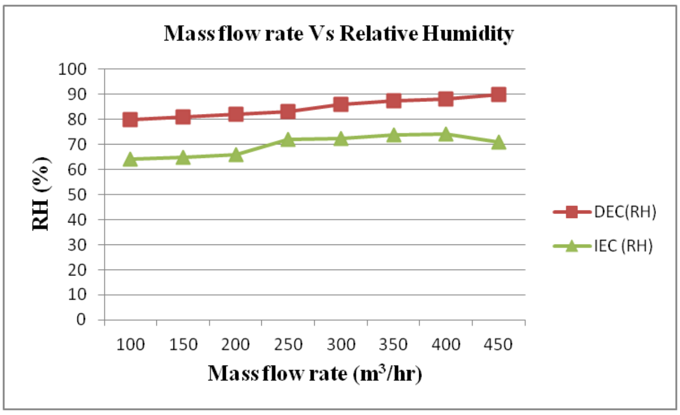

Fig. 8 relative humidity changes in DEC & IEC

The fig.5 shows that as the mass flow rate increases the temperature drop is also increases. After IEC the temperature dropped by 1 ºC as water temperature is below than air temperature. Fig. 6 shows that mass flow rate increases the cooling capacity of IEC is increases. Fig. 7 shows that the mass flow rate increases the COP of that system is increases. The fig. 8 shows that as the mass flow rate increases the RH of DEC & IEC increases.The effectiveness values of DEC and IEC varies with increase in air flow form 100 m^3/hr to 450 m^3/hr. Combined indirect-direct evaporative cooling systems can be beneficial in hot and dry climates and the inlet temperature of air can be reduced below its wet bulb temperature. Thus the normal operation of DEC can be extended into humid atmosphere and can provide comfort in most of the summer season.

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