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The Performance Comparison of the Experimental Study of Indirect Evaporative Cooler with Direct Evaporative Cooler

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Abstract
The evaporative cooling is environment friendly and efficient method of air condition. The efficiency of the evaporative cooling system is depending on the reduction in the outlet air dry bulb temperature, and will increase as the outside temperature increases. The efficiency is also depending on the reduction in outside air relative humidity. Due to higher relative humidity, its uncomfortable in certain localities due to heat and mass exchanging in direct evaporative cooling. In such hot and humid areas indirect evaporative cooler can provide the comfort conditions. Whereas the indirect and direct evaporative cooler combination can provide comfort conditions in the areas where alone direct evaporative cooler is not able to provide comfort conditions. In this paper, the results obtained by experimentation on the indirect evaporative cooler and the results from the literature only for the direct evaporative cooling are compared. The various performance parameters are inlet and outlet dry bulb temperature, change in relative humidity, cooling capacity and effectiveness.

Index Terms: Direct Evaporative cooler, Indirect Evaporative Cooler, wet bulb effectiveness, saturation efficiency, cooling capacity, dry bulb temperature, and relative humidity.

1. INTRODUCTION

The rise in the living standards and increasing temperatures due to global warming is leading to increased air conditioning demand for commercial, industrial and residential buildings. Due to the dependence on the resources and the rise in fossil fuel prices, there is restriction for the use of energy. This is forcing to take various measures to reduce energy demand, air conditioning is no exception. The building energy consumption is responsible for the major part of the world's total energy consumption. The indoor air temperature and relative humidity are the basic requirements to achieve the comfort conditions. The

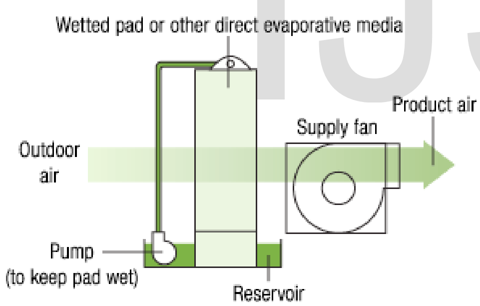

Figure 1 Direct Evaporative Cooler

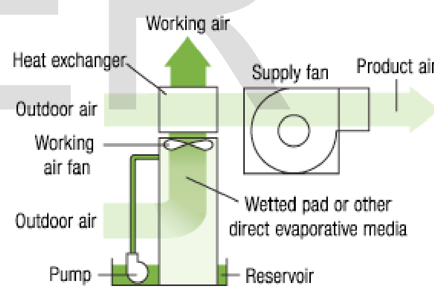

Figure 2Indirect Evaporative Cooler

evaporative cooling technology is energy efficient and eco-friendly technology, hence used in hot and dry climates. The evaporative cooling is achieved basically by direct evaporative cooling, indirect evaporative cooling and the combination of these two; with various configurations such as recovery, regenerative etc..

Direct evaporative cooling is popular method for the conditioning of the atmospheric air. The direct evaporative cooler as shown in figure 1above, utilizes fan to push the outside warm air through the porous pad, upon which continuous water spray is enabled, for the cooling of air. The heat is absorbed by the water as water evaporates from the wetted pad. The direct evaporative cooling is having the limitation that it can be only cooled up to the wet bulb temperature of the inlet air. In this heat and mass exchange process the sensible heat gets converted to the latent heat. Thus the direct evaporative cooling is associated with two main limitations that air contains moisture due to heat exchange with water and the reduction in the temperature can be only up to the wet bulb temperature of the inlet air. Where as in indirect evaporative cooling as shown in the figure 1(b) above, non-adiabatic evaporation takes place, resulting no moisture in outlet air.Camargo et.al; developed mathematical model to determine

heat and mass exchange for the saturation effectiveness, also experimented on the direct evaporative cooler to determine the convective heat transfer coefficient and compared with the mathematical model.[1]. Abdulrahman Th.Mohammad et.al; experimented on the direct evaporative cooling system in hot and humid regions. The cooler has the cellulose pad having surface contact area of 100m2/m3.The output temperature obtained between 27.5 to 29.4 deg whereas cooling capacity between 1.384 to 5.358 kw.[2]. Dai and Sumathy, experimented on cross flow direct evaporative cooler wherein honeycomb paper is used as heatand mass exchange medium. Also developed mathematical model for the interface conditions. The results shows that the honeycomb paper is good humidifier and cooling media to obtain minimum temperature and high humidity.[3]

Performance of two types of cellulose pads 5090 and 7090 investigated experimentally by Warke et.al; For experimentation Humidity variation, Pressure drop, effectiveness and evaporated water were checked for various velocities of inlet air. 50,100 and 150 mmthick padstested. Cellulose pad found most effective as compared to aspen and khus, with saturation efficiency of 90.37%.[4]. The comparative study of regenerative and cross flow indirect evaporative cooler carried out by Yugang Wang et.al; in order to clarify the applicability of both the evaporative coolers In order to understand the heat and mass exchange between the two exchangers the change in moisture content and temperature is studied.[5]. The experimental analysis done by Stefano Antonellis et.al, on a cross flow indirect evaporative cooler and evaluated the performance in the terms of the temperature drop, wet bulb effectiveness and fraction of evaporated water. The results shown that significant cooling capacity can be obtained in many operating conditions.[6] Stefano Antonellis et.al, tested the indirect evaporative cooler in view to minimize the water consumption, which remained 0.4 to 4 percent of the secondary air. The results shown that the performance is less dependent on the number and the size of the nozzles but strongly influenced by water flow rate. Also, counter flow arrangement gives better results than parallel flow nozzle arrangements.[7] The indirect evaporative cooler prototypes operating for two different modes is analyzed by E.V.Gomez, the wet operation or the evaporative cooling mode is effective as far as effectiveness and cooling capacity are concerned.[8] A comparative analysis of theoretical and experimental studies for a modified heat exchanger done by T.S.Bisoniya et.al, After comparison between the results they concluded that the model can be used to predict the performance of indirect evaporative cooler.[9]. Experimental evaluation of cooling performance of two stage indirect direct stage evaporative cooler carried out by Ghassem Heidarinejad et.al. The results shown that the effectiveness of indirect unit varies between 55 – 61 percent whereas that for two stage from 108 to 111 percent.[10]

2. Experimental Study

The experimental study performed to compare the results obtained by the experimentation on the indirect evaporative cooler and compared with the experimentation on the direct evaporative cooler by Abdulrahman Th. Mohammad, et.al, [2]. The schematic of the experimental arrangement is as shown in figure 2. The curves plotted for the results obtained between various parameters. The results plotted in the form of graphs. The various components of the indirect evaporative cooling system are indirect evaporative cooler made of polycarbonate, supply air fan, water tank, water pump, distribution piping with spraying system to enhance cooling. In view to evaluate the performance of indirect evaporative cooler in various climatic conditions and identify the effect of the operational parameters the experimental set up fabricated as shown in the figure. The polycarbonate wet surface heat exchanger used as indirect evaporative cooler, whereon the circulating pump is spraying the cooling water through the distribution piping. The blower and flow straighter is provided in air duct for the even distribution of supply air. The experimental set up consists of primary air simulator, mixing blower for primary and secondary air, fabricated flow straighter for primary and secondary air ducts, cross flow plate type indirect evaporative cooler unit, ambient room size 1m x 1m x 1m; for experimentation purpose, digital temperature relative humidity meters at inlet, outlet of indirect unit, secondary air mixing blower, flow straighter, water circulating pump with distribution system for indirect evaporative cooling systems along with the water distribution scheme including rotameters for indirect evaporative cooling systems having flow adjustment arrangements. The details of the equipment used are as follows:

Primary air simulator: The supply air fan is a centrifugal fan for the simulation of the air with frequency inverter to adjust the flow rate of supply air. The primary air simulator consists of centrifugal fan, with frequency inverter for flow rate adjustment, as per the experiment requirement, electrical heaters, which is discharging hot vapors for humidifying air between heater and mixing blower. In order to get the steady air flow the flow straighter is provided in the square inlet duct. Before the flow straighter, mixing blower is provided to facilitate uniform temperature and humidity. This module adjusts the primary air flow, inlet air temperature and relative humidity.

Secondary air duct: secondary air duct is open to atmospheric air, wherein heating element is housed to preheat the secondary air as per requirement. Mixing blower is housed to ensure uniform air flow. After air passes through blower it passes through flow straighter which is fabricated inside the air duct. The secondary air is passed through the alternate wet passages to extract heat from primary air, and then exhaust to atmosphere.

Indirect evaporative cooling unit includes a polycarbonate constructed wet surface cross flow plate heat exchanger with proper sealing at the meatal casings from insides. The other specifications of heat exchanger are height 0.5m, width 0.45m and 0.4m length. The spacing of the plates is 5mm, the thickness of the plate is 0.3 mm.

A water circulating pump is provided to take the water from the water sump below the heat exchangers within the .

3. Design Considerations:

Following are some of the considerations that are taken in to account in designing the set up in order to insure maximum flexibility.

1. Provision of adjustable flow rate for the primary air.For this particular experimentation the air flow rate kept constant at 50 percent.
2. Secondaryair is atmospheric air at normal conditions.

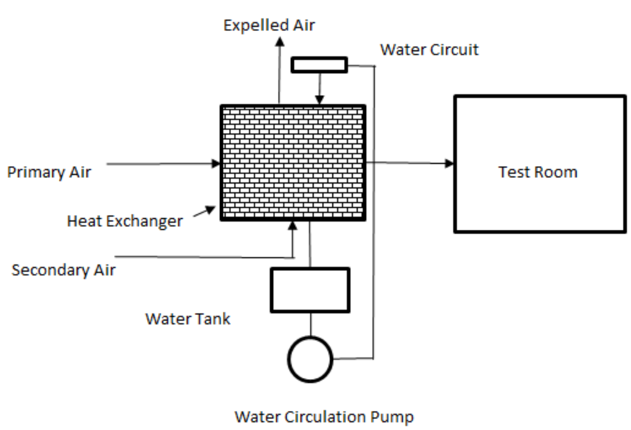

Figure 3 Scheme of indirect evaporative cooler

housing. The distributing piping to the indirect evaporative cooling system is branched from the discharge of the pump. The flow meters with valve for regulating water flow to the indirect evaporative cooler are provided in the distributing pipes to the indirect evaporative cooling system.

The specifications of the 'HTC – 1' make digital temperature relative humidity indicators used are :
Temperature range (-10 to +50ºC),
Temperature Accuracy - ±0.1ºC,
Humidity Range – 10% ~ 99% RH,
Humidity Accuracy - ±0.5%RH,
Power supply – 1.5V (AAA size 1 Battery),
Product dimension – 100 x 93 x 20mm.
Total 2 digital meters are used in the experimental set up.
One pre-calibrated rotameters are installed in the discharge lines of the recirculation water pump –for indirect evaporative cooler.
Average air velocity is measured at appropriate locations using anemometer (Accuracy - and Resolution - according to ASTM D3464.
The temperature and Relative humidity (RH) are measured at following locations:

i. Air temperature and Relative Humidity before the indirect evaporative cooling unit.
ii. Air temperature and Relative Humidity after the indirect evaporative cooling unit

3. In this experimentation the water flow rate is kept at 50 percent, though there is provision of adjustable flow rate for water for indirect evaporative cooler.

The operational specifications of the test set up are as given above in experimental set up, which meets these requirements.

4. Data Calculation :

Thermal effectiveness:

The following parameters are defined. For the wet surface operation we need to define wet bulb effectiveness, since the air can be cooled to the wet bulb temperature of the inlet air.

$$\varepsilon_{WBT} = \frac{T_1 - T_2}{T_1 - Twb_i} \quad \text{...} [1]$$

Where,
ε_{WBT} = Wet bulb effectiveness
T_1 = Dry bulb inlet temperature.
T_2 = Dry bulb outlet temperature.
T_{wbi} = Wet bulb temperature of inlet air.
Cooling Capacity:

The amount of energy involved in the process can be determined by the cooling capacity

$$Ecc = m(h_1 - h_2) \text{...} [2]$$

h_1 = specific enthalpy of outside air at inlet in kJ/kg
h_2 = specific enthalpy of outside air at outlet in kJ/kg
Since, there is no change in the humidity at outlet of the exchanger, the amount of the cooling involved can be calculated as follows;

$$Ecc = mc_{pa}(T_1 - T_2) \text{...} [3]$$

Cpa = specific heat of air (J/kg° C)

5. Results and Discussion :

The experimental analysis of the performance of the indirect evaporative cooler is carried out by doing experiments on set up, at constant air flow and water flow rates, of 50 percent respectively. The results obtained after the experimentation on the indirect evaporative cooler were plotted for the purpose of comparison with that of the direct evaporative cooler to understand the differences. As shown in the figure 4 below, temperature drop is depending on the inlet temperature of out side air dry bulb temperature. As the outside temperature increases the temperature drop increases. However in this experimentation for the purpose of comparison the flow rate of the air is kept constant at 50 percent, though the drop in temperature is also directly proportional to the air flow rate within certain limit. The temperature drop will be higher for lower air volume flows due to increased residence time. Higher temperature drops are also due to water film at secondary side of exchanger. The drop in temperature is almost similar but lower in case of indirect evaporative cooler due to sensible cooling only.

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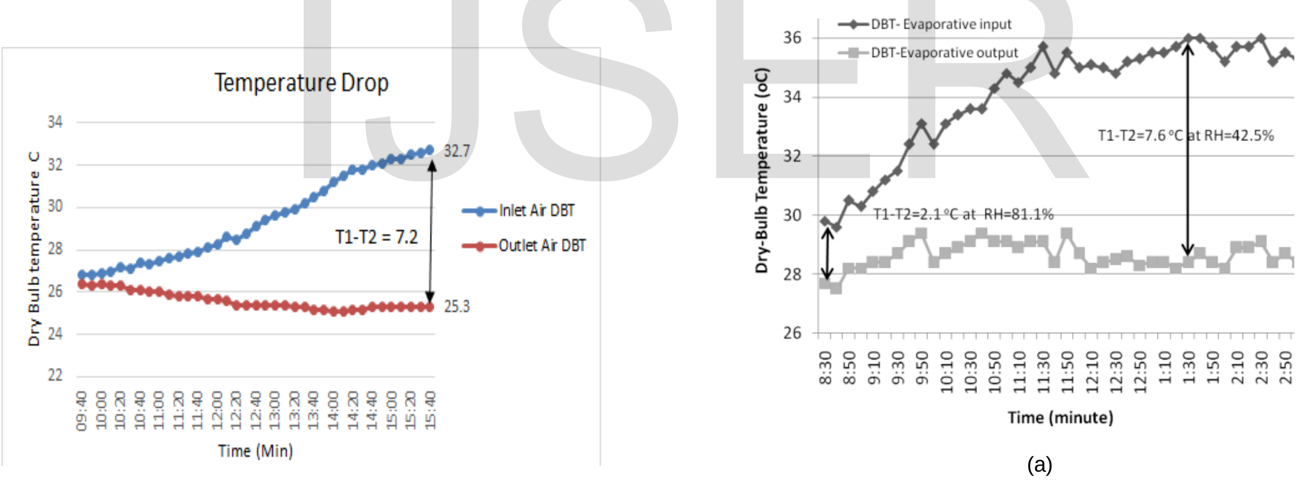


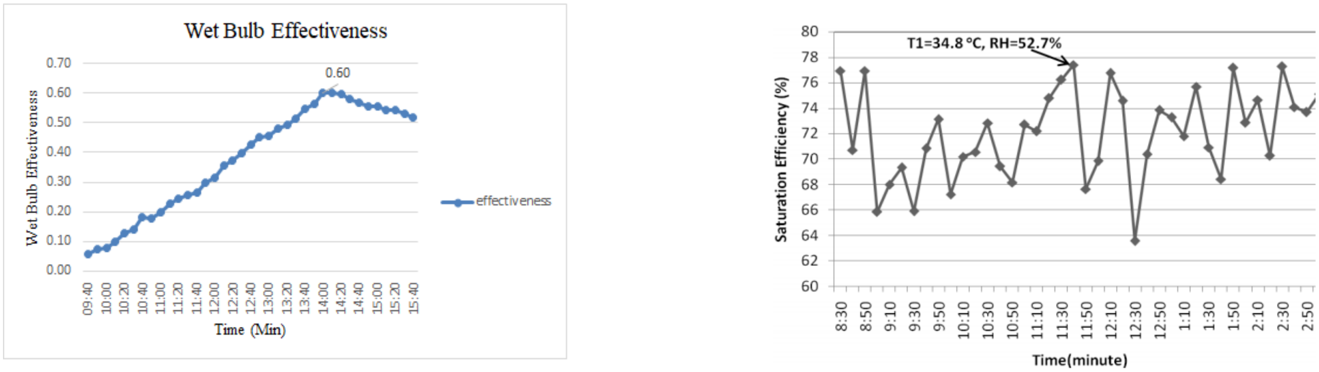
(b) (a)

Figure 4 Temperature drop (a) Indirect evaporative cooler (b) Direct evaporative cooler.

The inlet air conditions for the direct evaporative cooler were 29.6 to 36 deg while for the experimentation on the indirect evaporative cooling system were 26.8 to 32.7 deg C. Average air velocity 2.5 m/sec against that of 5.5m/sec for direct evaporative cooler. The water flow rate for the experimentation kept at 50 ltr/min. The variation of the dry bub temperature in inlet and outlet is as shown in fig 4 (b)

The result shows that maximum possible temperature that can be achieved is 7.6 deg at relative humidity of 42.5% whereas minimum drop in temperature is 2.1 deg with relative humidity of 81.1 %. The indirect evaporative cooler gives maximum temperature drop of 7.2 deg.at relative humidity of 24% relative humidity and minimum of 26.4 deg and inlet relative humidity of 53%.

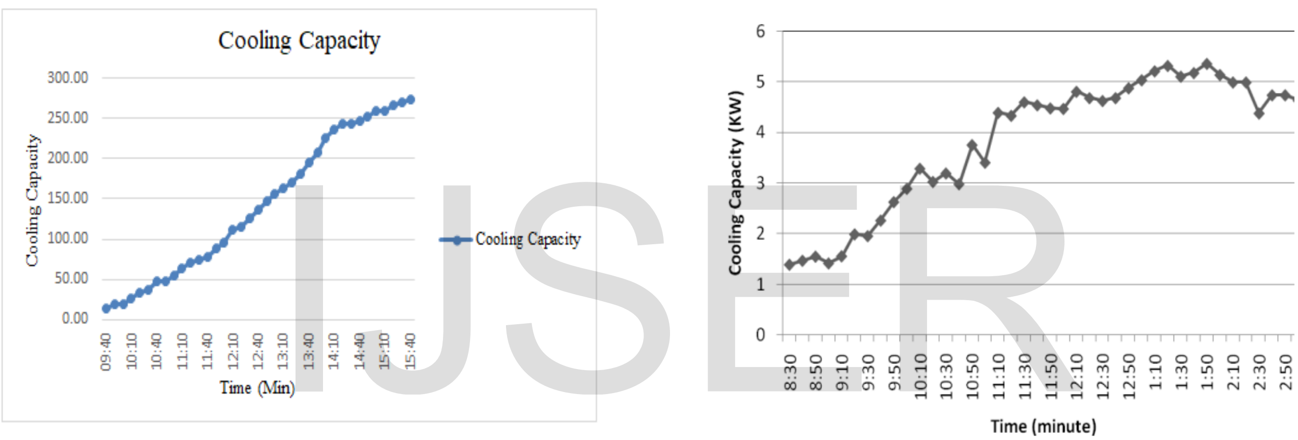
The figure 5 shows the comparison of the wet bulb thermal effectiveness of the indirect evaporative cooling system and the saturation efficiency of the direct evaporative cooler from the literature. The wet bulb effectiveness at average air flow rate of air flow is as shown in figure 5(a) below. At higher outside air dry bulb temperature the effectiveness is higher at 60 %, but is less than the direct evaporative cooler shown in figure 5(b). This is because the heat and mass exchange occurring inside the direct evaporative cooler, whereasthere is only sensible cooling in indirect evaporative cooler.



(a) (b)

Figure 4 (a) Wet bulb effectiveness IEC (b) Saturation Efficiency direct evaporative cooler

The variation of the cooling capacity is shown in figure 5. The indirect evaporative cooling system is shown as figure 5(a) whereas that obtained by the experimentation on the direct evaporative cooler from the literature is shown in figure 5(b).



(a) (b)

Figure 5 Cooling capacity (a) Indirect evaporative cooler (b) Direct evaporative cooler

As far as the performance of indirect evaporative cooling system is concerned, the cooling capacity is the key factor. It is also plotted for average air flow. The trend for the cooling capacity presents similar to the wet bulb effectiveness. If the flow rates of the air are higher then the cooling capacity increases slightly. But the cooling capacity increases slightly at higher flow rates of air. This is due to air flow rate inside the system, which is considered by cooling capacity. This is not represented minimum. The cooling capacity is proportional to the drop in the dry bulb temperature of inlet air. Hence for by the thermal effectiveness. Also, even if due to longer residence time for the lower air flow rates; the temperature drops are higher, the quantity of air handled is also lower resulting in to lower amount of energy utilized. Whereas the experimentation on the direct evaporative cooler shows between 1.3 to 5.3 kW. The maximum cooling capacity is seen at 1:50 PM while at 8.30 am its

constant mass flow rate of air it increases with increase in the drop in the dry bulb temperature

6. Conclusion:

The results of the comparison between the experimentation on the indirect evaporative cooler and that the direct evaporative cooler tested in earlier literature shows that: The saturation efficiency and the wet bulb effectiveness are depending on the outside air temperature. Higher the temperature higher effectiveness and saturation efficiency.

The cooling capacity improves significantly with higher outside air dry bulb temperature for both direct and indirect evaporative coolers.

Due to sensible cooling of air the effectiveness values are less as compared to saturation efficiency due to direct heat and mass exchange occurring that in the direct evaporative cooler.

The indirect evaporative cooling system can be utilized effectively in hot and humid localities due to no moisture content at the outlet of exchanger whereas the direct evaporative cooling is effective in dry areas only.

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