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Experimental Investigation of an Indirect Evaporative Cooling System

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Abstract: This research presents the experimental investigation of an indirect evaporative cooling system in Iraqi climate, this system aims to cool the outside fresh air by water evaporation without increasing in moisture content of the evaporative cooled which is one of the most important disadvantages of the traditional evaporative air coolers. The system composing from the sensible heat exchanger that cools the outside fresh air associated with the evaporative cooling tower. Part of produced cold air extracted to the cooling tower allowing the cooling tower allowing the cooling tower to produce cold water at temperatures less than the system inlet wet bulb temperature. The results of the system show the capability to provide a reduction in energy consumption up to 40% in comparison with mechanical vapor compression systems. The system COP and effectiveness reached 8.82 and 0.768, respectively. Also, the cooling system provides 19.5 at 35°C system inlet temperature. On depending on the testing results, this system can reduce the gap between evaporative air cooling systems and mechanical vapor compression systems as an environmentally clean and energy efficient system.

Key words: Indirect, evaporative cooling, dry, wet bulb temperature, wet bulb effectiveness, sensible heat exchanger

INTRODUCTION

Many countries suffering from the problem of high dry bulb temperatures in summer season which carries the burdens of high power demand of air condition equipment's, a large percentage of power burdens can be solved by using evaporative cooling technology, the effectiveness of evaporative cooling is depending on the advantage of the large difference between the dry bulb temperature and the wet bulb temperature which can use positively in evaporative cooling system. Iraq is one of these countries that have desert climate and characterized by summer high dry bulb temperature and dryness, also long summer period that could span for seven months from April to October, the daytime often exceed 49 °C with average daily temperature over 37°C (Azooz and Talal, 2015) in most of the summer season as a results large amount of the country power consumption is for Air Conditioning (A/C). This indirect evaporative cooling technology is promising to develop in the near future due to its very low energy consumption and high efficiency in its range of applications (Porumb *et al*., 2016).

Many researches investigate the performance of indirect evaporative cooling, Maheshwari *et al*. (2001) have estimated the energy-saving potential of an Indirect Evaporative air Cooler (IEC).The study made in Kuwait from April to October where the average daily WBT ranges from 8-25°C, this study present an analytical evaluation using the filed performance results of a 1180 L/sec of air. Evaluating cooling capacity of indirect evaporative cooling is found to be 2.4TR for coastal areas and 3.4 TR for interior areas. The required Power to achieve the mentioned cooling capacity with an air-conditioner for the coastal and interior area is 3.85 and 4.9 kW and only 1.11 kW power was needed by the indirect evaporative cooler to provide the same cooling.

Chaktranonda and Doungsong (2010) have evaluated experimentally the saving in energy in the split-type air conditioner comparing with an evaporative cooling system. The results revealed that the ambient air temperature had been much influenced by the power consumption of compressor and COP. When the temperature raised by 1°C, the electrical power of the split-air conditioner increased by around 4% where the evaporative cooling system can reduce the power consumption about 15% and can increase COP up to 48%.

Jaber and Ajib (2011) have analyzed an indirect evaporative cooling system installed in Jordan which perfectly represents the Mediterranean climate with the operation of this system; the energy consumption and carbon emission based gases were seriously reduced without influencing the comfort conditions. Consistent with the data, if 500,000 Mediterranean buildings used indirect evaporative cooling system instead of conventional air conditioning, the annual estimated energy saving is about 1084 GWh the

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annual total avoided of CO_2 emission is estimated to be 637,873 ton. It took <2 years to get the payback.

Gomez *et al*. (2012) experimentally study a polycarbonate-made indirect evaporative cooling system with two operation modes. The first mode is the outdoor air as the primary air and the exhaust air leaving the climate chamber as the secondary air of the heat exchanger. The second mode when remaining other conditions same, added up a water spraying measure into the exhaust air flow. The experimental results showed that the IEC system could reach higher cooling capacity and also improve cooling effectiveness when spraying water against the exhaust air. Further, higher outdoor air temperature or air flow rate enhanced cooling performance of the system.

Reddy *et al*. (2012) present design of small IEC, the system developed as a cross-flow heat exchanger and evaluating the performance under controlled environmental conditions. The system experimental results showed a satisfactory agreement with the analytical values. The analytical results show that higher inlet temperature and low inlet humidity of the comfort air results in an increase in both cooling capacity and cooling effect. a lower velocity of comfort air increasing the cooling effect but the cooling capacity decreases.

Qiu (2007) tested on a small scale IEC system. The experimental results indicated that the values given by the product catalogs were much lower than the real performance of the IEC system. The reduction in performance lied in the poor water distribution of the system which gave only 1/2-2/3 of the flat-plate surface when in operation. To resolve the problem, the researcher installed a top-water sprayer and had it integrated with a PV panel which had to provide electrical energy needed for pump and fans operation. The modified unit was re-tested and the results showed that the COP and cooling capacity of the new system was 3 times higher than the old one. The drop in temperature of the primary air between the inlet and outlet of the unit was in the range 3-8°C.

This research is aim to constructing and testing of an indirect evaporative cooling unit used to produce fresh, cooler air with less humidity than normal direct evaporative cooling unit and consequently decrease the energy demand in the hot climate area (Iraq) to overcome the problem of high energy demand used for cooling purposes.

MATERIALS AND METHODS

In order to test the proposed of improving the indirect evaporative cooling, the prototype of the system has been designed and constructed. The test set up had to be of a sufficient scale to ensre that the experimental results could b e extrapolatedto larger systems. The system layout is shown in Fig. 1 and 2. The components described as following.

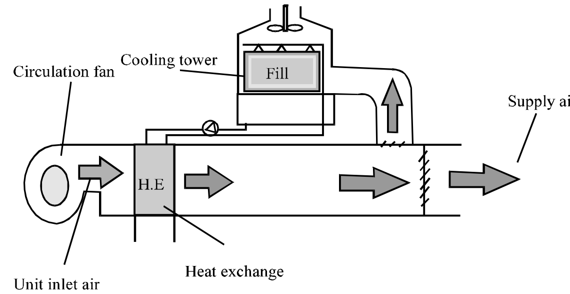

Fig .1: Combined system layout


Fig. 2: Photographs of the system

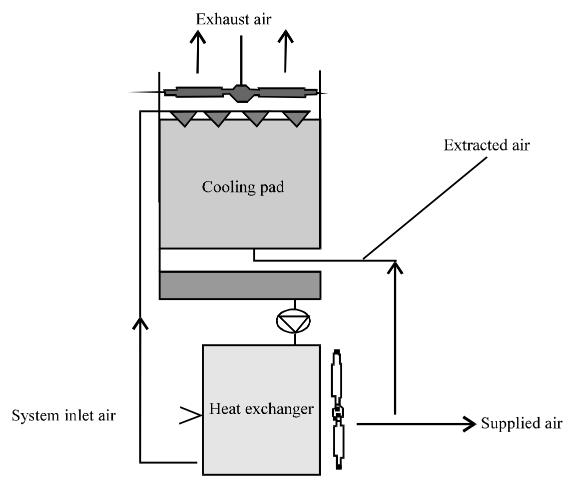

Fig. 3: External regenerative indirect evaporative cooling components

System components: Figure 3 illustrates the external regenerative indirect evaporative cooling. Which depending on producing cold water from cooling tower that used a part of the air that has been already cooled by the heat exchanger, the heat exchanger used the supplied cold water that supplied from the cooling tower to cool

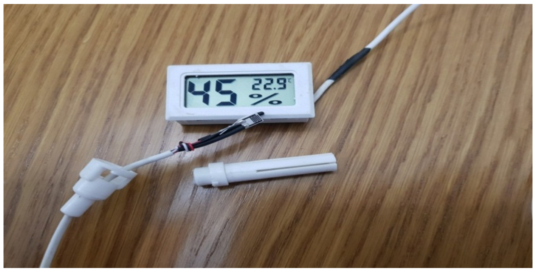

Fig. 4: Digital air hygrometer and thermometer

outside fresh air, There is a of list the heat exchanger parameters. The indirect evaporative regenerative cooling part consists of:

- The quasi-counter flow heat exchanger to cool the fresh air
- Counter-flow induced Water cooling tower
- Water circulation system (pump, piping)

Measuring instruments: A collection of calibrated measures instrument were used to measure temperature, humidity, water flow and air flow rate.

Digital hygrometer and thermometer instrument: this instrument used to measure the air dry bulb temperature and relative humidity at different locations, Fig. 4 show the digital air hygrometer and thermometer instrument.

Digital thermometer: This digital thermometer with mini LCD used to read the inlet and outlet water temperature of the cooling tower also water temperature in the water basin in Direct evaporative cooling section.

Digital air flow meter: This kit used to measuring air flow rate in unit inlet and outlet and existing air from the cooling tower. Figure 5 show the used digital air anemometer.

Digital water flow meter: Figure 6 show the digital water flow meter used to measure the water flow rate between cooling tower and heat exchanger.

Performance parameters: IEC standards indicated that the performance of an IEC system could be represented by several characteristic parameters including wet-bulb effectiveness; cooling capacity; power consumption; energy efficiency (COP) air extraction ratio and air flow rate. the detailed of these parameters as follows:

Wet-bulb effectiveness: Wet bulb effectiveness is defined as a parameter describing the extent approach of the

Fig. 5: The digital air anemometer

Fig. 6: The digital water flow meter used to measure the water flow rate between cooling tower and heat exchanger

outlet product air temperature against the wet-bulb temperature of the unit inlet air and can be written as:

$$\varepsilon_{wb} = \frac{t_{db,in}\ t_{db,out}}{t_{db.in} - t_{wb,in}} \quad (1)$$

Cooling capacity: The cooling capacity refers to the change in enthalpy during air processing and is expressed as follows:

$$Q_{total} = \rho_{air} V_{out} \left(i_{db,in} - i_{db,out} \right) \quad (2)$$

Since, the air is cooled at the constant moisture content in IEC throw dry heat exchanger, the enthalpy change could be represented by the temperature reduction of the air throw heat exchanger. For this reason, the above equation could be rewritten as:

$$Q = C_{air} \rho_{air} V_{out} \left(t_{db\ in} - t_{db,out} \right) \quad (3)$$

Power consumption: An evaporative cooling system consumes much less electrical power than conventional refrigeration mechanical compression air conditioning systems. Unlike the conventional air conditioning systems that use electricity to drive energy intensive compressor and fan/pump an evaporative cooling system uses electrical power to drive only a fan and pump.

Energy efficiency or (COP): Energy efficiency or Coefficient of Performance (COP) is the ratio of the cooling capacity to the power consumption of the system. This term can be expressed as:

$$\text{Energyefficency} = \frac{Q}{Pc} = \frac{C_{air}\,\rho_{air}\,V_{out}\left(t_{db\ in}-t_{db,out}\right)}{Pc} \tag{4}$$

If COP is multiplied by a unit conversion factor of 3.413 then the COP is converted into the Energy Efficiency Ratio (EER).

RESULTS AND DISCUSSION

The effect of water flow rate: Figure 7 show the effect of water flow rate in the heat exchanger and the ability to remove the heat it can be seen that increasing in flow rate case to increases heat exchanger cooling capacity with limited range and then decline when the water flow rate exceed 0.1 L/sec this drop in heat exchanger capacity occurred due to the increasing of tower outlet water temperature as shown in Fig. 8. Whichit's aggravated with an increasing in the air temperature entering to cooling tower as cleared in Fig. 9.

The effect of unit inlet air flow rate on system daily performance: In order to test the effect of inlet air flow rate to the system on the indirect evaporative unit, two conditions of flow rates were tested (0.425, 0.48 m^3/sec). Figure 10 and 11 depict that the increasing of inlet air flow rate led toIncreasing the outlet air temperature due to two effects, first the effect is the increasing of amount of air which led to decreasing the time of heat exchange with heat exchanger, second is the increasing in the temperature of the outlet water of cooling tower water because the increasing air DBT that entering to cooling tower. Increasing the unit supplied air DBT temperature due to the increasing of second stage inlet air DBT.

The effect of inlet dry bulb temperature: Figure 12 shows the effect of the inlet air DBT on the unit wet bulb

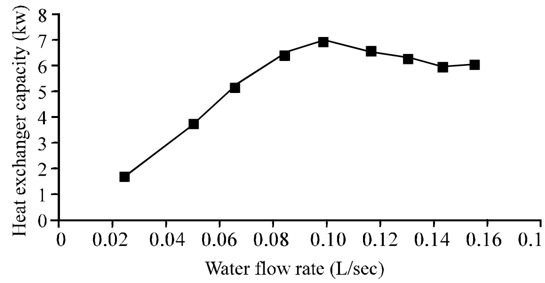

Fig. 7: The heat removed from the heat exchanger with various water flow rates, (Unit inlet DBT = 40°C , inlet WBT = 20°C, inlet volumetric air flow rate = 0.425 m^3/sec, extraction rate = 35%)

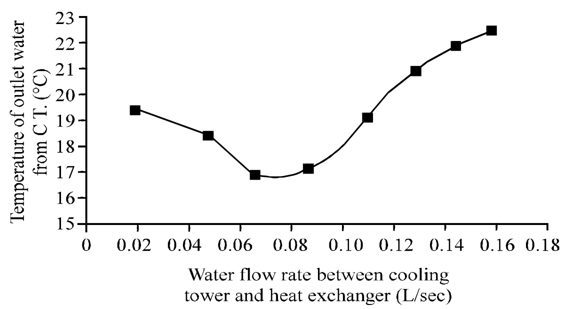

Fig. 8 : The effect of water flow on cooling tower water outlet temperature (Unit inlet DBT= 40°C, inlet WBT = 20°C, inlet volumetric air flow rate = 0.425 m^3/sec, air extraction rate = 35%)

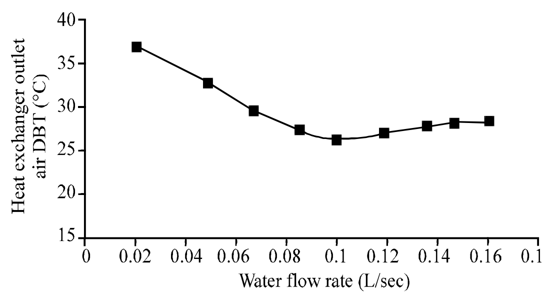

Fig. 9: The effect of water flow between the cooling tower and heat exchanger on heat exchanger outlet air DBT (Unit inlet DBT = 40°C, inlet WBT = 20°C, inlet volumetric air flow rate = 0.425 m^3/sec, extraction rate = 35%)

effectiveness as well as system outlet air DBT when inlet air volumetric flow rate is 0.425 m^3/sec, it's clear that the wet bulb effectiveness increased with the increasing of inlet air DBT, this increasing because there is a higher ability of heat and mass transfer between air and water when the DBT increases with constant humidity ratio.The

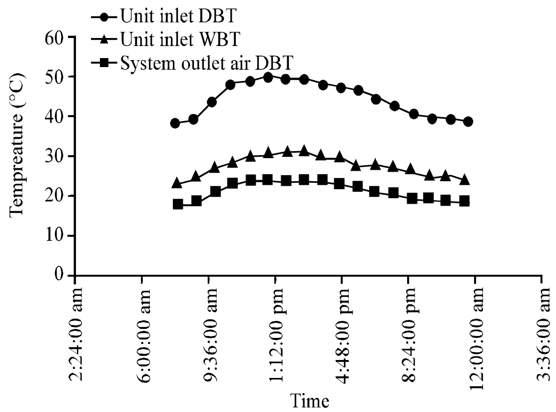

Fig. 10: Daily unit temperature readings with volumetric inlet air flow rate = 0.425 m³/sec, HE water flow rate = 0.1 L/sec, E.R. = 0.35%

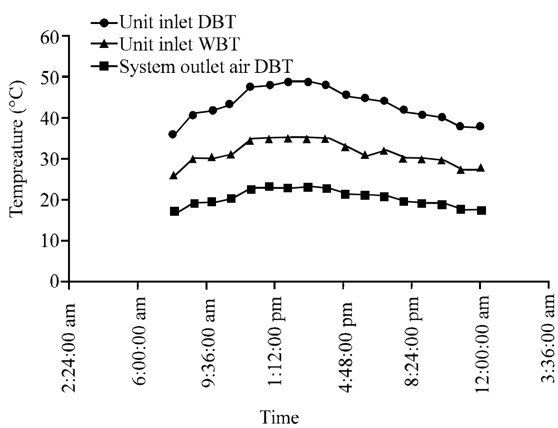

Fig. 11: Daily temperature readings when volumetric inlet air flow rate = 0.48 m³/sec, HE water flow rate = 0.1 L/sec, ER = 0.35%

increasing of air inlet DBT led to increasing the system outlet air DBT as illustrated in Fig. 13. At constant humidity ratio and 45°C inlet dry bulb temperature the unit could reach wet bulb effectiveness equal to 0.768 and the lowest outlet air temperature reached when the system inlet DBT was 32°C.

The effect of Extraction Ratio (ER) on unit wet bulb effectiveness and unit COP: Four extracted air flow rates (30, 40, 50 and 60%)has been tested as shown in Fig. 14, its show that the tower wet bulb effectiveness is proportional positively with increasingthe air extraction rate because the increase of extraction ratio led to increase evaporation rate of water in the tower. On other hand the

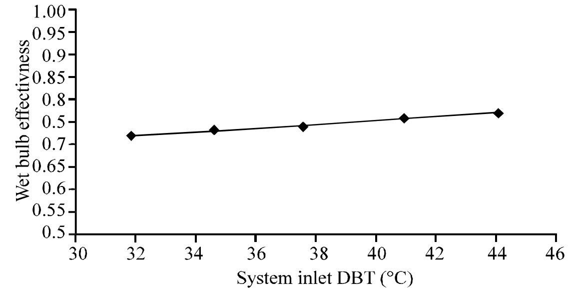

Fig. 12: Wet bulb effectiveness versus inlet air temperature (Inlet air volume flow rate = 0.425 m³/sec, inlet air humidity ratio = 5 g water/kg dry air, ER = 35%, water flow rate = 0.1 L/sec)

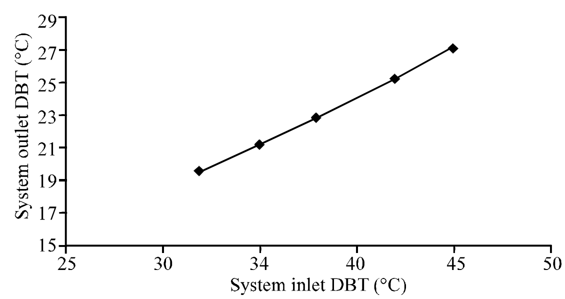

Fig. 13: Wet bulb effectiveness versus inlet air temperature (Inlet air volume flow rate = 0.425 m³/sec, Inlet air humidity ratio = 5 g water/kg dry air, ER = 35%, water flow rate = 0.1 L/sec)

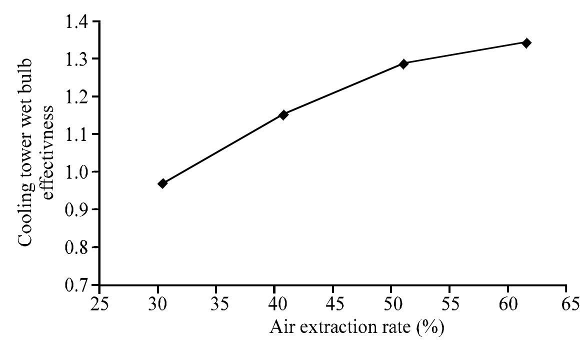

Fig. 14: Wet bulb effectiveness versus extraction rate % Inlet air DBT = 38°C, Inlet air volume flow rate = 0.425 m³/sec, Inlet air humidity ratio = 5g water/kg dry air)

increasing in extracted air is improve the unit COP to reach maximum COP at 40% extraction rateandthen declinesdue to the reduction in unit supplied air flow rate which effected on unit capacity (Fig. 15).

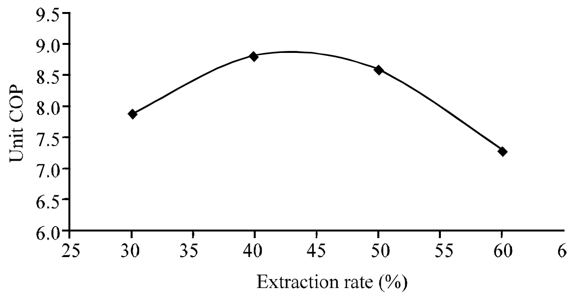

Fig. 15: Unit COP versus extraction rate% (Inlet air DBT = 38°C, Inlet air volume flow rate = 0.425 m^3/sec, Inlet air humidity ratio = 5)

CONCLUSION

The performance of experimental indirect evaporative cooling unit is tested in climate conditions of Iraq. Results showed that the unit has good potential to provide comfort conditions in hot and dry regions with good energy saving potential and there is a possibility to manufacturing this unit in large capacities as a central cooling system.

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