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Research Article

Experimental Performance of Two-stage Evaporating Cooling System

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Abstract: Space cooling has become a major source of energy use, such that, during the hot summer months, cooling performance of two-stage indirect/direct evaporative cooling system is experimentally investigated in the various simulated climatic conditions. For this purpose, a two-stage evaporative cooling experimental setup consisting of an indirect evaporative cooling stage (IEC) followed by a direct evaporative cooling stage (DEC) was designed, constructed and tested. Due to the wide variety of climatic conditions in Erbil, Results show that under various outdoor conditions, the effectiveness of IEC stage varies over a range of (55–65) % and the effectiveness of two stage IEC/DEC unit varies over a range of (90-110) %. Aspects of achieving comfort conditions and power saving have been investigated with related excess water consumption. Considering the evaporative comfort zone, this system can provide comfort condition in Erbil-Iraq where direct evaporative alone is not able to provide summer comfort condition. More than 60% power saving could be obtained by this system in comparison with mechanical vapor compression systems with just 55% increase in water consumption with respect to direct evaporative cooling systems. The final outlet temperature of air in two stage modes IEC/DEC ranges between 23 ^{0}C and 25 ^{0}C.
Keywords: (IDEC) Indirect-Direct Evaporative Cooler, Cooling Capacity, power saving.

INTRODUCTION

Indirect-direct two stage evaporative cooling system consists of indirect cooler in the first stage and direct cooler in second stage. Indirect cooling is accomplished with either plate type or tube type heat exchanger. The plate type heat exchanger consists of number of tube forming alternate channels for primary and secondary air. Secondary air channels are kept wet by flow of water from upper side. Direct cooling in second stage is achieved by passing the air from indirect stage over the cooling media saturated with water. Hot and dry weather conditions exist in summer months of April and May and June, July and August reaches 45 ^{0}C to 47 ^{0}C in Erbil Iraq. Dry bulb temperatures (DBT) are reaching 40 ^{0}C with relative humidity as low as 30 %. This offers an excellent opportunity to use evaporative cooling as an alternative to conventional cooling systems.

Evaporative cooling has been used for thousands of years in various forms for comfort cooling and is still in common use around the world because of it's simplicity, low cost and effectiveness. Unfortunately, many owners of buildings and specifiers of cooling equipment do not seem to realize that it is effective in all areas, and not limited to the hotter, drier climates. ASHRAE Handbook, 1995, chapter 47, Evaporative Air Cooling notes "...dry bulb temperature reduction due to the evaporation of water always results in a lower effective temperature, regardless of the relative humidity level" and that ".(evaporative cooling) can provide relief cooling of factories almost regardless of geographical location."

In a large number of industries it is normal in hot weather to experience increased heat-related illness, lower productivity and increased absenteeism among workers. Many of these industries cannot afford the tremendous costs of conventional mechanical refrigeration or air conditioning, while they can afford evaporative cooling. Quoting from ASHRAE Handbook, 1995, Chapter 47, "evaporative cooling can alleviate this heat problem and contribute to worker efficiency with improved morale. If the heat problem is not alleviated, increased absenteeism, high labor turnover and dangers to health and safety will be common during the summer months. Production declines in cooled plants may range from 25% to 40% of normal on hot days.

Evaporative cooling is an environmentally friendly and energy efficient method for cooling buildings in hot and dry regions. Iran as a multi-climate country demands a variety of cooling systems to achieve optimized energy consumption, reduce emission, and provide summer comfort condition. Many types of natural and passive methods were used for cooling buildings in traditional architecture. All of these methods have been worked based on natural ventilation. Wind tower and shape of building are the main elements in these traditional cooling methods, which deviate and convey outside air to buildings [1].Evaporative cooling is secondary to refrigeration, but the evaporative cooling system is 60-80% cheaper to buy and operate. It is affordable for the moderate income group. It can competitively cool hot, thinly constructed mills, factories, workshops, foundries, powerhouses, farm buildings, canneries, etc., where refrigeration air conditioning is prohibitively expensive due to the large floor areas[2].experimentally verified the performance of indirect evaporative cooler to pre cool the mixed air in a variable air volume system in laboratory environment. They compared energy savings and reduction in peak electric demand of IEC with conventional air conditioning [3].

If a first indirect stage is added to a second direct stage, a two-stage indirect/direct cooler is obtained which cools the air more than a stand-alone DEC unit. A two-stage air-conditioner combining indirect and direct processes is gaining popularity in places where the higher wet bulb temperatures (i.e. higher ambient humidity) does not permit sufficiently low indoor temperatures supplied from a simple direct air-conditioner. The first stage cools air without adding moisture and in the second stage, moisture is added. In comparison with mechanical vapor compression systems, two-stage evaporative cooling systems have advantageous features as follows [4]:

- Reduction in power consumption and the required power generation capacity.
- Reduction in the combustion rates of fossil fuels in power plants and associated emissions of air pollutants;
- Using water as the working fluid instead of CFCs;
- Ability of achieving suitable level of humidity in rather dry regions;
- Supplying fresh air in air conditioning process;
- Simple manufacturing technology;

Studied the performance of an indirect/direct evaporative cooling system and the effect of coupling the system with a cooling tower. In this combined system, the cooling tower removes the thermal load added to the system during air pre-cooling and as a result, higher thermal effectiveness is achieved. Results show that the highest thermal effectiveness is obtained for the combined system, which is followed by a two-stage indirect/direct evaporative cooling unit [5].

Constructed an experimental setup of dry surface two-stage evaporating cooling unit and tested it in the Kuwait environment. The system consisted of an indirect evaporative unit followed by a direct evaporative cooling unit. During the summer season of Kuwait with dry bulb temperatures higher than 45 ^{o}C the system was operated. The system operation was a function of the packing thickness and water flow rate of the DEC unit. Other parameters include the water flow rate to the IEC unit and the mode for operating the IEC heat exchangers. Results showed that the effectiveness of the IEC/DEC system varies over a range of 90–105% [6].

MATHODOLOGY

Evaporative Cooling Systems

Not much attention has been given to evaporative cooling even though, in many arid and desert regions such as Botswana, evaporative cooling devices are used. These often use the speed of prevailing winds that often blow during the daytime, mainly in the afternoon, from a constant general direction. In such cases it is possible to cool small buildings by passive evaporative cooling devices. Evaporative passive coolers humidify and cool ambient air without using fans [7].

An evaporative cooling system is an air conditioning system in which air is evaporative cooled just like how, the body perspires on a hot day and this moisture evaporates into the air in contact with our skin. Because the evaporation process absorbs heat, our skin feels cool. The faster the air moves over the skin, the cooler one feels. An ideal evaporative cooler basically consists of a wetted medium, a fan (which is usually a centrifugal fan to provide the required system total pressure loss and a lower noise level), and a sump at the bottom. For, water spraying systems, a circulating pump and piping connection are needed to distribute water evenly. A float valve replenishes water lost through evaporation and also allows for a constant bleed to dilute and flush out insoluble mineral salts accumulating in the sump.

Principle of operation of evaporative cooling.

Whenever dry air passes over water, some of the water will be absorbed by the air. The hotter and drier the air, the more water that can be absorbed. This happens because the temperature and the vapor pressure of the water and the air attempt to equalize. The evaporative cooler is shown in figure 1.

Fresh outdoor air 1, is drawn through the moist pads by a belt driven centrifugal/propeller fan 5. As the air passes through the pads 2, evaporation takes place; liquid water molecules become gas in the dry air 4, a process that uses energy to change the physical state. Heat moves from the higher temperature of the air to the lower temperature of the water 3. As a result, the air is cooled and its moisture content is elevated, while its 'Wet Bulb Temperature' (WBT) remains constant. The cool, filtered air is circulated via ducting through grills or diffusers, 6 replacing the warm, stale air which is forced out through open windows, doors and diffusers [8].

Types of evaporative cooling systems
Two principle methods of evaporative cooling are:-
1) Direct cooling: In direct cooling water evaporates directly into the airstream, thus reducing the air's dry-bulb temperature while humidifying the air.

2) Indirect cooling: In indirect cooling, one stream of air called primary air is cooled sensibly (without addition of moisture) with a heat exchanger, while the secondary air carries away the heat energy from the primary air. Direct and indirect processes can also be combined (indirect/direct). The effectiveness of either of these methods is directly dependent on the low wet bulb temperature in the supply airstream.

Direct Evaporative Cooling (open circuit).
Direct evaporative cooling introduces water directly into the supply airstream (usually with a spray or some sort of wetted media). As the water absorbs heat from the air, it evaporates and cools the air. In direct evaporative cooling the dry bulb temperature is lowered but the wet bulb temperature remains unchanged. In operation, a blower pulls air through a permeable, water-soaked pad. As the air passes through the pad, it is filtered, cooled, and humidified. A recirculation pump keeps the media (pad of woven fibers or corrugated paper) wet, while air flows through the pad. To ensure that the entire media is wet, more water is usually pumped than can be evaporated and excess water drains from the bottom into a sump. An automatic refill system replaces the evaporated water as shown in fig.2.

The efficiency of direct cooling depends on the pad media. A good quality rigid cellulose pad can provide up to 90% efficiency while the loose aspen wood fiber pad shall result in 50 to 60% contact efficiencies.

Indirect Evaporative Cooling (closed circuit).
Indirect evaporative cooling lowers the temperature of air via some type of heat exchanger arrangement, in which a secondary airstream is cooled by water and which in turn cools the primary airstream. The cooled air never comes in direct contact with water or environment. In indirect evaporative cooling system both the dry bulb and wet bulb temperatures are reduced.

Indirect evaporative coolers do not add humidity to the air, but cost more than direct coolers and operate at a lower efficiency as shown in fig.3. The efficiency of indirect cooling is in the range of 60-70%.

Two-stage Indirect/direct Evaporative Cooling
Two stage evaporative coolers combine indirect with direct evaporative cooling. This is accomplished by passing air inside a heat exchanger that is cooled by evaporation on the outside. In the second stage, the pre-cooled air passes through a water-soaked pad and pickup humidity as it cools. Because the air supply to the second stage evaporator is pre-cooled, less humidity is added to the air, whose affinity for moisture is directly related to temperature. The two-stage evaporative cooling provides air that is cooler than either a direct or indirect single-stage system can provide individually. In many cases, these two-stage systems provide better comfort than a compressor-based system, because they maintain a more favorable indoor humidity range.

An advanced two-stage evaporative cooler uses 100 percent outdoor air and a variable speed blower to circulate cool air. Two-stage evaporative coolers can reduce energy consumption by 60 to 75 percent over conventional air conditioning systems, according to the American Society of Heating and Engineers (ASHRAE). Yet this relative improvement depends on location and application as shown in figure 4.

Theory

Saturation effectiveness of Direct Evaporative Cooling is

$$\varepsilon_e = \frac{t_1 - t_2}{t_1 - t'} \text{ x } 100 \qquad (1)$$

Where:
$\boldsymbol{\varepsilon_e}$ = Direct evaporative cooling or saturation effectiveness
$\mathbf{t_1}$ = Dry-bulb temperature of entering air, °C
$\mathbf{t_2}$ = Dry-bulb temperature of leaving air, °C
$\mathbf{t'}$ = Thermodynamic wet-bulb temperature of entering air, °C

And effectiveness of indirect Evaporative Cooling is

$$\varepsilon_e = \frac{t_1 - t_2}{t_1 - \text{ts}} \text{ x } 100 \qquad (2)$$

Where:
$\boldsymbol{\varepsilon_{Ie}}$ = Indirect evaporative cooling effectiveness, %
$\mathbf{t_1}$ = Dry-bulb temperature of entering primary air, °C
$\mathbf{t_2}$ = Dry-bulb temperature of leaving primary air. °C
$\mathbf{t_s}$ = Wet-bulb temperature of entering secondary air, °C

And Overall cooling efficiency of two stage cooler can be estimated

$$\eta_o = \frac{t_1 - t_3}{t_1 - t_{w1}} \qquad (3)$$

Experimental system and procedures
Experiment device:-
To evaluate performance of IEC/DEC system in various climatic conditions and in order to investigate effect of operational parameters, an experimental setup was designed and constructed as shown in Figure 5. Experimental device consist of:- (Duct, Blower, Pipe for cross air, Pipe for water spray ,Fins, Exhaust fan,

Tank and water pump, Splash (evaporator pads),Tank for water spray in the top of splash, Electrical source, Main electric cut, Electrical switch, Thermocouples with thermometer and support).

- Primary air simulator including a centrifugal fan equipped with a frequency inverter to adjust flow rate, electrical this module adjusts flow rate, temperature, and relative humidity in primary air stream. A straighter was provided to achieve airflow uniformity and a free rotational mixer downstream of simulator is utilized to obtain temperature and relative humidity homogeneity.
- Secondary air simulator similar to primary air simulator in secondary air stream.
- Indirect evaporative cooling IEC unit including heat exchanger as IEC unit and consist of a Pipes that through air, pipes for water spray ,fins ,exhaust fan, tank and water pump. Water is distributed over indirect system using proper spray nozzles. Specifications of this heat exchanger.
- Direct evaporative cooling DEC unit a 15 cm thick pad as DEC unit, a water circulating pump and proper spray nozzles.

  Air temperature and relative humidity (RH) are measured in the following positions:

  1- Dry bulb temperature and relative Humidity of ambient.
  2- Dry bulb temperature after the IEC unit in primary flow.
  3- Dry bulb temperature after the IEC unit in secondary flow.
  4- Dry bulb temperature after the DEC unit.

RESULT AND DISCUSSION

At present in most hot and dry regions, direct evaporative cooler is a common cooling system providing comfort for residential and commercial buildings. In regions with high wet bulb temperature where the direct systems do not provide comfort condition, mechanical vapor compression cooling systems are used.

According to test results, using of IEC/DEC system can be recommended in Erbil Iraq to achieve indoor comfort condition.

DEC systems provide comfort condition in a wide range of hot season, but IEC/DEC systems can provide comfort condition during the whole of hot season. In addition, due to obtaining lower dry bulb and wet bulb temperatures by using IEC/DEC systems, higher level of comfort condition can be achieved. In these regions, IEC/DEC systems can provide comfort condition, also leading to decrease electrical energy consumption.

In addition, IEC system can be used as a pre-cooling unit before mechanical cooling systems in climates with higher wet bulb temperature forming a hybrid evaporative mechanical cooling system. In this case, the energy consumed by indirect evaporative cooling stage is much less than the energy saved from reducing the load on refrigeration system. As a result, the overall energy consumption of the system will reduce. Another saving could result from the reduction in size of the refrigeration equipment required. Indirect evaporative cooling may also reduce the total time the refrigeration equipment must be operated during year.IEC effectiveness varies between 55 and 65 % and IEC/DEC effectiveness over a range of 90–110%.

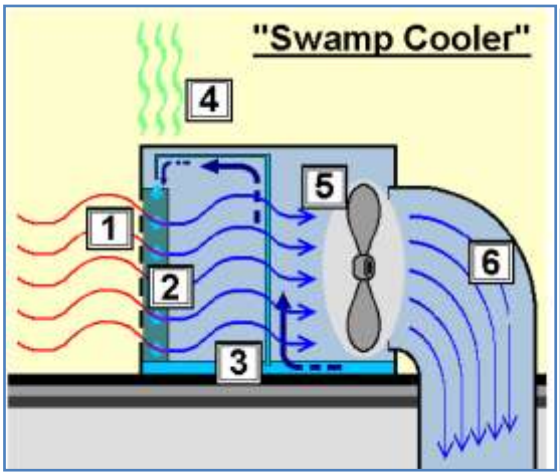

Fig.1. Direct evaporative (swamp) cooler.

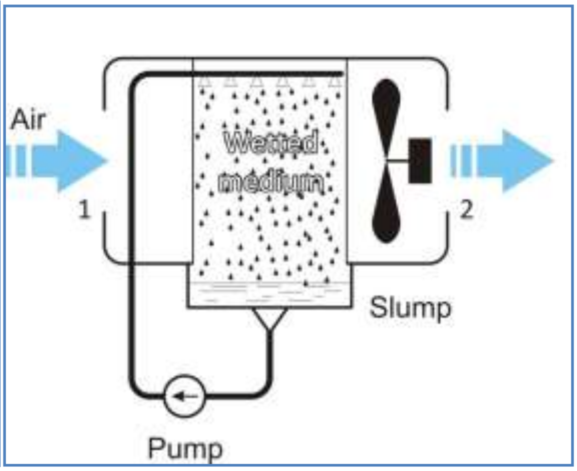

Fig.2. Direct Evaporative Cooling (open circuit)

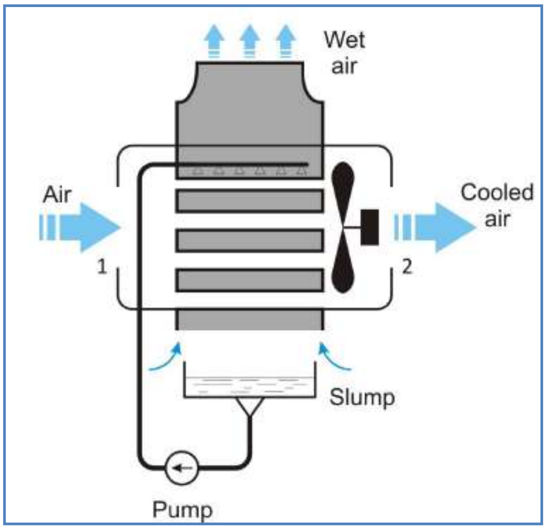

Fig.4. Two-stage Indirect/direct Evaporative Cooling

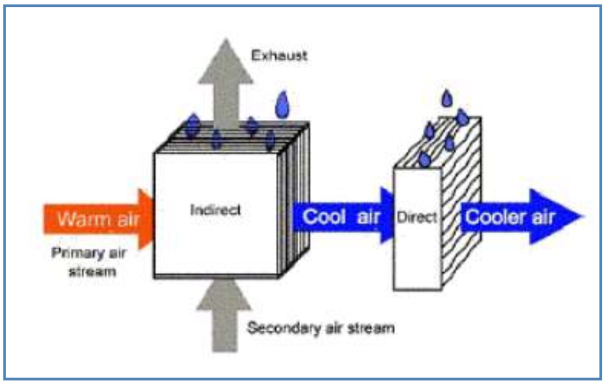

Fig.3.Indirect Evaporative Cooling (closed circuit).

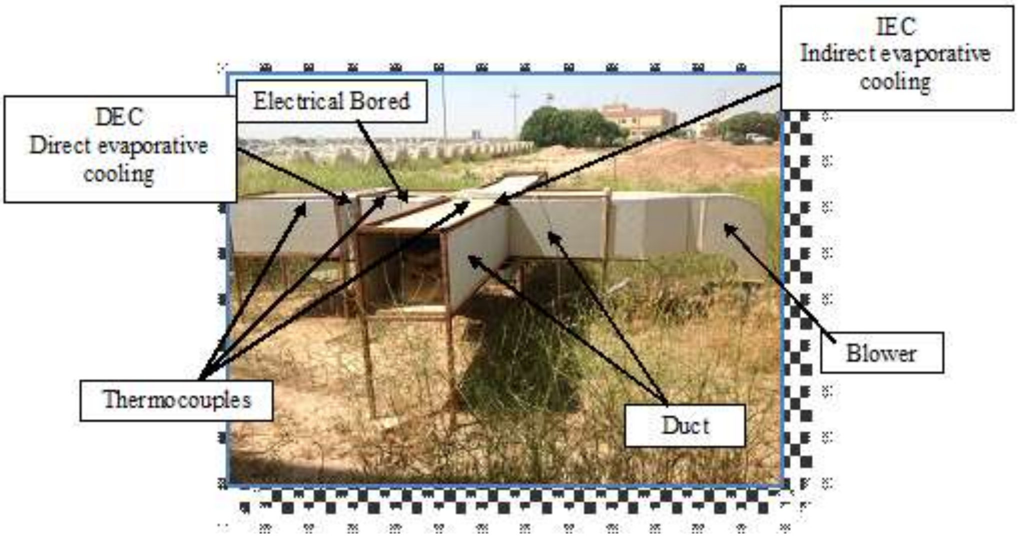

Fig.5. experimental device Two-stage Indirect/direct Evaporative Cooling

Conclusions

In conclusion, evaporative cooling has made summers more bearable for thousands of years and with 21st century technology provides effective, economical, environmentally friendly, and healthy cooling. Evaporative cooling comes in three flavors: direct, indirect, and indirect/direct. Evaporative cooling works well in the desert like environments, alone or as a supplement to a chiller or direct expansion refrigerant system.

The performance of experimental two-stage indirect/direct evaporative cooling system is evaluated in various Erbil City. Results show that in this system has high potential to provide comfort conditions in Erbil where at present stand-alone direct evaporative coolers cannot provide comfort conditions. This system can be used instead of mechanical vapor compression systems, so leading to decrease electrical energy consumption.

It is observed that IEC effectiveness varies between 55 and 65% and IEC/DEC effectiveness over a range of 90–110%. Results show that average water consumption of two-stage evaporative cooling system is 40% more than direct evaporative cooling system and power consumption is 33% of mechanical vapor compression cooling systems, so this cooling system can be used in various climatic conditions as an environmentally clean and energy efficient system.

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