Performance Analysis of Two-stage Evaporative Cooler: A Review

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Abstract
An evaporative cooler is eco-friendly as they use a natural process, i.e., evaporation of water, to cool the air. Evaporative coolers have two major advantages over traditional air conditioners: energy efficiency and sustainability. Both are due to the fact that evaporative coolers use far less electricity to operate. Evaporative cooling systems contain no harmful synthetic refrigerants. In this paper, we have tried to show the research work has been done on a two-stage evaporative cooler in the recent past, on the basis of the various performance test.

Keywords: *Evaporative cooling; Heat exchanger; Effectiveness; Two-stage.*

I. INTRODUCTION

Evaporative cooling systems have attracted much attention as an alternative to the conventional air conditioning system because it helps to save refrigerated power costs. Evaporative cooling technology is more sufficient and eco-friendly technology. Therefore, in the hot and dry tropical regions, the evaporative cooling technology can be used for saving a large amount of energy. Evaporative cooling is not only limited to thermal comfort but also an effective method of storage of foods and vegetables of moderate respiration rate.

Evaporative cooling is used in many other applications, such as

- Animal housing facility cooling
- Electronics and optic fiber equipment cooling
- Turbine engine air intake cooling
- Exterior spot cooling
- Greenhouse, laundries, and manufacturing process cooling
- Power plant evaporative cooling towers

Benefits of using evaporative cooling in its growing climatic ranges are:

- Lower operating and power cost
- Mostly applicable for rural region
- Maintenance cost is much lower
- Ventilating effect is also great if needed
- Better air distribution without ducts
- Usually lower outdoor noise levels
- Evaporative cooling units remove moist of the air contaminants, such as dust, dirt, bacteria, soluble gases, and nutrients
- Applicable in the domestic and industrial application in wide-scale
- It gives high effectiveness

II. DIRECT EVAPORATIVE COOLER

The direct evaporative cooling (DEC) system uses a cellulose media with the water contact surface where the air is passed through it at a uniform rate. The principle underlying direct evaporative cooling is the easy conversion of sensible to latent heat. Non-saturated air is cooled by exposure to free and colder water, both thermally isolated from other influences as shown in Fig. 1. Some of the air's sensible heat transfers to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapor and diffuses into the air. That exchange of sensible for latent heat tends to progress until the air is saturated and air and water temperatures and vapor pressures equalize. It is called adiabatic saturation because no external heat is involved; saturation is approached purely by conversion of the air's existing sensible heat.

A. Limitations

- Due to the increase in relative humidity, which may cause flu-like illness when coming in direct exposure to human
- Evaporative cooling pads required a continuous water supply
- It is only suitable for dry and hot climate

III. INDIRECT EVAPORATIVE COOLER

Indirect evaporative cooling (IEC) cools air by the evaporation of water not contacting it and so does not increase the cooled air's moisture content. Indirect evaporative cooling involves two streams of air passing through coolers simultaneously, but not contacting each other. As usually identified:

• **Primary Air**: the air being cooled that will later become supply air for cooling rooms.

• **Secondary Air**: the air that contacts and helps evaporate the water that cools the heat exchanger surfaces that cool the primary air. The secondary air usually comes from outdoors and is discharged there again after use.

The hearts of all indirect evaporative coolers are the heat-exchange surfaces that separate the primary air from the secondary air and the water the latter is evaporating. Those surfaces absorb heat from the primary air and transfer it to moist secondary air, which carries it away and discards it outside. The surfaces may be metal or plastic plates, sheets, or tubes or even revolving wheels of porous metal. They must conduct heat readily, keep the two air streams apart, and resist corrosion. [1]

Limitation

- Effectiveness is less

IV. TWO-STAGE EVAPORATIVE COOLER (INDIRECT/DIRECT)

To avoid the high relative humidity of direct evaporative cooler and by considering the low effectiveness of indirect evaporative cooler, the combined of both the system is called two-stage evaporative cooler as shown in Fig. 2. The principle of a two-stage evaporative cooler is to reduce the wet-bulb temperature of outdoor air before entering the DEC unit. The heat exchange process reduces the dry bulb temperature of the air stream without changing its humidity. After that, the air stream is introduced into the DEC unit. As a result, the air temperature approaches the wet-bulb temperature of the pre-cooled air. This temperature is lower than the wet-bulb temperature of the ambient air.

A. Thermal performance

Thermal performance analysis of two-stage evaporative cooler is obtained using below-mentioned equations.

a) Adiabatic effectiveness (ε) of two-stage Evaporative cooler: It is the ratio of actual drop in dry bulb temperature of the air to the maximum possible temperature drop or wet-bulb depression.

$$\varepsilon = \frac{T_{di} - T_{do}}{T_{di} - T_{wi}}$$

b) Cooling capacity of Two stage evaporative cooler: Cooling capacity = $m_a \times (h_i - h_o)$

c) Efficiency of Evaporative pad (η):

$$\eta = \frac{T_{db\ air\ entering\ pad} - T_{db\ air\ leaving\ pad}}{T_{db\ air\ entering\ pad} - T_{wb\ air\ entering\ pad}}$$

V. LITERATURE SURVEY ON A TWO-STAGE EVAPORATIVE COOLER

Many researchers had performed the worked on two-stage evaporative cooler. Heidarinejad et al. [2] used two air simulator to simulate outdoor design condition of different cities in primary and secondary airstream, and results show that effectiveness of IEC stage varies over range of 55-61% and effectiveness of Indirect/Direct stage varies over a range of 108-111% under various outdoor condition. They compared the power consumption of Indirect/Direct evaporative cooler with mechanical vapour compression system. It was found that the more than 60% power saving could be obtained by the Indirect/Direct evaporative cooler.

Jain [3] developed and tested the two-stage evaporative cooler by using plate type heat exchanger as IEC unit and humidifier, which is stuffed with wooden shave as DEC unit. The result shows that the effectiveness varies from 110% to 120% and relative humidity of room air was observed from 50%-75% against the 15-40% of ambient air. Kim and Jeong [4] calculated the cooling performance of a 100% outdoor air system integrated with two-stage evaporative cooler. It was observed that effectiveness of two-stage varies from 83.4-97.8% in an intermediate season where outdoor air temperature varies from 20-25°C range and humidity vary from 20-80%.

Jaafarian and Kazemian [5] developed a mathematical model of two-stage evaporative cooling, which consists of two direct evaporative coolers and a heat exchanger. It was noticed that the overall effectiveness of system is more sensitive to evaporative pad efficiency than that of overall heat transfer coefficient.

El-Dessouky et al. [6] constructed a two-stage evaporative cooler and tested in Kuwait environment during the summer season when dry bulb temperature is higher than 45°C. They showed that the efficiency of IEC unit, DEC unit, and IEC/DEC unit is in range of 20-40%,63-93% and 90-120%, respectively.

Sharma and Darokar [7] designed two-stage evaporative cooler and provided two air simulator to simulate outdoor design condition in primary and secondary air stream. They showed that the effectiveness of IEC and IEC/DEC varies between 55 -61% and 108-111%, respectively. They also showed that the average water consumption of two-stage evaporative cooler is 55% more than the direct evaporative cooler and power consumption was 33% of mechanical vapour cooling system.

Mohammed [8] developed an experimental setup on two-stage evaporative cooler. He used heat exchanger as IEC unit and 15 cm thick pad as DEC unit. It was observed that the IEC effectiveness varies from 55 and 65% and IEC/DEC effectiveness over a range of 90-110%. It was also seen that the average water consumption of two-stage evaporative cooling system was 40% more than the direct evaporative cooling system.

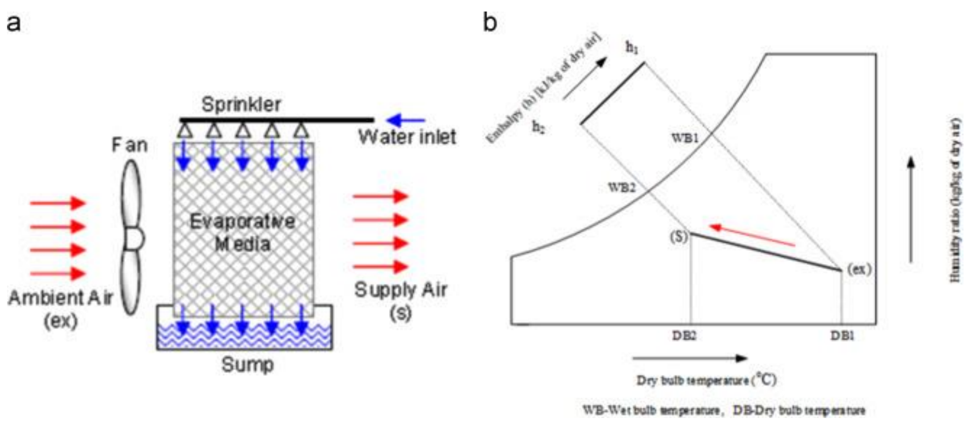
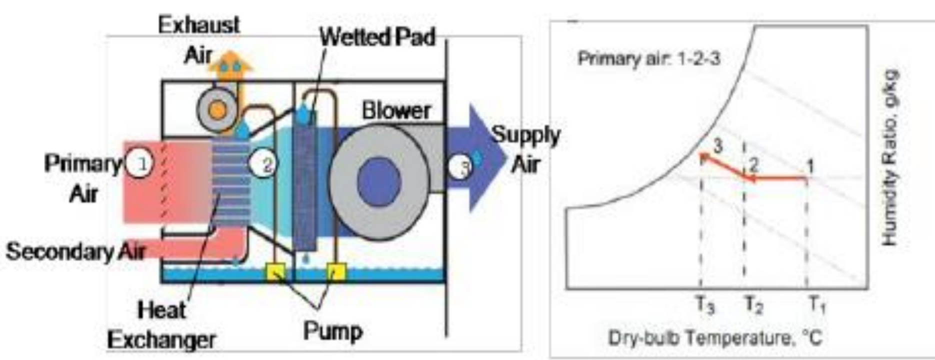


Figure 1: Direct Evaporative cooling system (a) Schematic diagram (b) and psychometric process [9]



(a) Basic structure (b) Psychometric process

Figure 2: Two-stage Evaporative cooling system (a) Schematic diagram (b) and psychometric process [10]

Al-Juwayhel et al. [11] experimentally investigated four different arrangements of an evaporative cooler and found that the IEC/DEC had the highest EER than the other three arrangements. It was also found that the DEC had the lowest effectiveness.

Alklaibi [12] experimentally investigated the internal two-stage evaporative cooler and compare its thermal performance with direct evaporative cooler. Results showed that the efficiency of internal two-stage evaporative cooler fluctuates around 0.70, while the efficiency of direct evaporative cooler fluctuates around 0.66. The results also showed that the efficiency of direct evaporative cooler increases by 12% and the internal evaporative cooler increases only by 5% when fan speed switches from high to low.

VI. CONCLUSIONS

From the above review paper, following conclusions are made:

- Two-stage evaporative cooler consumes less power than conventional air conditioner.
- Effectiveness of two-stage evaporative cooler is more than another cooling system.
- The EER of two-stage evaporative cooler has best value.
- Pad thickness and material, fan speed, water circulation is the main factor that affects the effectiveness of evaporative cooler.
- Effectiveness is also depending on outdoor temperature and relative humidity.

Nomenclature

T_{di}	Inlet Dry bulb temperature
T_{do}	Outlet Dry bulb temperature
T_{wi}	Inlet Wet bulb temperature
m_a	Mass flow rate of air
h_i	Enthalpy(kJ/kg) of entering air
h_o	Enthalpy(kJ/kg) of leaving air
T_{db}	Dry bulb temperature

Abbreviation

IEC	Indirect evaporative cooler
DEC	Direct evaporative cooler
EER	Energy efficiency ratio

Greek symbols:

ε	Effectiveness
η	Efficiency

REFERENCES

1. Watt, J.R.: Evaporative Air Conditioning Handbook. Chapman and Hall, 1986
2. Heidarinejad, G., Bozorgmehr, M., Delfani, S., Esmaeelian, J.: Experimental investigation of two-stage indirect / direct evaporative cooling system in various climatic conditions. Build. Environ. 44, 2073–2079 (2009). doi:10.1016/j.buildenv.2009.02.017
3. Ã, D.J.: Development and testing of two-stage evaporative cooler. 42, 2549–2554 (2007). doi:10.1016/j.buildenv.2006.07.034
4. Kim, M.H., Jeong, J.W.: Cooling performance of a 100% outdoor air system integrated with indirect and direct evaporative coolers. Energy. 52, 245–257 (2013). doi:10.1016/j.energy.2013.02.008
5. Mohammad, J., Ehsan, K.M.: Performance analysis of a two-stage evaporative cooler. 403, 1–8 (2017). doi:10.1051/meca/2017013
6. El-Dessouky, H., Ettouney, H., Al-Zeefari, A.: Performance analysis of two-stage evaporative coolers. Chem. Eng. J. 102, 255–266 (2004). doi:10.1016/j.cej.2004.01.036
7. Sharma, A., Darokar, H.: Two Stage Indirect / Direct Evaporative Cooling. 41–46 (2018)
8. Kareem Mohammed, A.: Experimental Performance of Two-stage Evaporating Cooling System. Sch. J. Eng. Technol. Sch. J. Eng. Tech. 1, 122–127 (2013)
9. Mujahid Rafique, M., Gandhidasan, P., Rehman, S., Al-Hadhrami, L.M.: A review on desiccant based evaporative cooling systems. Renew. Sustain. Energy Rev. 45, 145–159 (2015). doi:10.1016/j.rser.2015.01.051
10. Amer, O., Boukhanouf, R., Ibrahim, H.G.: A Review of Evaporative Cooling Technologies. Int. J. Environ. Sci. Dev. 6, 111–117 (2015). doi:10.7763/ijesd.2015.v6.571
11. Al-Juwayhel, F., El-Dessouky, H., Ettouney, H., Al-Qattan, M.: Experimental evaluation of one, two, and three stage evaporative cooling systems. Heat Transf. Eng. 25, 72–86 (2004). doi:10.1080/01457630490486292
12. Alklaibi, A.M.: Experimental and theoretical investigation of internal two-stage evaporative cooler. Energy Convers. Manag. 95, 140–148 (2015). doi:10.1016/j.enconman.2015.02.035