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Investigation of an evaporative air cooler using solar energy under Algerian climate

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Abstract

This paper presents an investigation of a direct evaporative air cooler (DEAC) under Algerian climate, at the city of BECHAR. We carried out the theory and design of the DEAC. Simulation is done for an evaporative air cooler for three successive months June, July and August under TRNSYS environment. Measured weather data of the selected site are generated by METEONORM software. Result showed that the maximum depression of the dry bulb temperature reached is about 18.86°C and the Energy Efficiency Ratio (EER) is calculated. Evaporative cooling equipments work well in the hot and arid southern regions, which constitute practically the two third of the country. They have no impact whatsoever on the environment. Energy consumption is much less than in classical air conditioning units this is why these systems can be powered by solar photovoltaic panels.

Keywords: Evaporative cooling; Evaporative cooler; Rigid pad media; Simulation.

1. Introduction

Evaporative air coolers often referred to as “swamp” coolers have been popular for years because they offer an economical alternative to conventional air conditioning systems in a hot and dry climate. Compared to air conditioning units, evaporative air Coolers also operate without ozone harming chlorodifluromethane (HCFCs) used by refrigeration based systems.

An evaporative air cooler is a device that cools air through the simple evaporation of water. It is especially well suited for climates where the air is hot and humidity is low. In Algeria, the southern regions are good locations for the implementation of this equipment if sufficient water is available. In these climates, the installation and operating cost of an evaporative air cooler can be much lower than that of air conditioning units. However, evaporative cooling and vapor-compression air conditioning are

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sometimes used in combination to yield optimal cooling results. Some evaporative coolers may also serve as humidifiers in the heating season.

Watt and Lincoln [1] report that half of the conventional cooling devices in the south west USA were replaced by simple direct evaporative air coolers, this would save 18 million barrels of oil per year. Although direct evaporative cooler is simple and inexpensive, it has the disadvantage that if the ambient wet-bulb temperature is higher than about 21°C, the cooling effect is not sufficient for indoor comfort cooling [2]. However, direct evaporative coolers should not re-circulate indoor air.

This paper presents a theoretical analysis, feasibility and performances simulation of direct evaporative air cooler under Algerian climate specifically Bechar city.

Nomenclature

Q	heat transfer rate, W
h	heat transfer coefficient, W/m²°C
A	Wet surface area of the panel, m²
ΔT_{LM}	Log mean temperature difference, °C
T	Temperature, °C
ε	Panel effectiveness, -
m	Flow rate, kg/s
cp	specific heat at constant pressure, kJ/kg°C
EER	Energy Efficiency Ratio, BTU/W-hr
W	Power consumption, W
ΔT	Wet bulb depression, °C
FI	Feasibility index
V	Volume of the room,m3
ACR	Air change rate, 1/hr
WC	Water consumption, kg/hr
x	Humidity ratio of air, (kg water/ kg dry air)
ρ	Air density, kg/m3
Re	Reynolds number
Pr	Prandlt number
L	Pad thickness, m
L_e	Characteristic length, m
Nu	Nusselt number
Subscripts	
wb	Wet bulb

2. Direct evaporative air cooler

Single stage or direct evaporative coolers are the most common and are categorized by pad type, "Fiber" pads or "Sheet" pads[3].

Fiber Pads provide a wettable surface through which air is circulated. The most common pads are shredded aspen wood fibers sometimes called excelsior. There are other synthetic fiber pads but high quality aspen pads set the performance standard. Pads vary in thickness, quality and cost. Thicker, 2 inch pads are generally better. Fiber pads will normally need to be replaced annually as mineral deposits buildup.

Rigid-Sheet Pads are made of a stack of corrugated material and are usually 100 to 200 mm thick [3]. These pads are more expensive than fiber pads but can last for many years when water quality is properly maintained. Operating characteristics of DEAC with various wetted media is shown on table 1.

Table 1- Operating characteristics of DEAC with various wetted media [4]

Type of medium	Saturation efficiency	Face velocity (m/s)	Remarks
Air washer	0.8 –	2 – 4	Pad thickness of 5 cm
Evaporative Pad	0.9	0.5 – 1.5	
Rigid media	0.8	2 - 3*	Rigid media is usually designed for a face velocity of 2 to 3 m/s: 1.3
	0.75 –		m/s for 100 mm and 2.2 m/s for 150 mm [5]
Rotary wheel		0.5 - 3	
	0.95		

Rigid pads should be washed down at the end of the cooling season before any accumulated scale dries and hardens.

Typically, acceptable performance figures for direct evaporative coolers are [6]:

- A saturation efficiency of the cooling process of 70% or better.
- A maximum indoor air velocity of 1 m/s.
- The air temperature of the indoor space should be around 2°C higher than the discharge air temperature and its relative humidity should be below 70%.
- The resulting temperature of the indoor space should be about 4°C below the outdoor dry-bulb temperature.

3. Rigid media evaporative air cooler

Blocks of corrugated material make up the wetted surface of rigid-media direct evaporative air coolers (Figure 1). Materials include cellulose, plastic, and fiberglass that have been treated to absorb water yet resist the weathering effects of water. The medium is cross-corrugated to maximize mixing of air and water. The medium has the desirable characteristics of low resistance to airflow, high saturation effectiveness, and self-cleaning by flushing the front face of the pad.

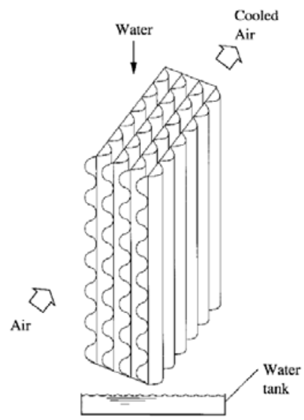

Fig. 1. Rigid media evaporative cooler [4]

Direct evaporative air coolers using this material are built to handle as much as 280 m3/s with or without fans [5]. Saturation effectiveness varies from 70 to over 95%, depending on media depth and air velocity. Air flows horizontally while the re-circulating water flows vertically over the medium surfaces by gravity feed from a flooding header and water distribution chamber. The header may be connected directly to a pump that may re-circulate the water from a lower reservoir, which is constructed of heavy gage corrosion-resistant material. The reservoir is also fitted with overflow and positive flowing drain connections. The upper media enclosure is fabricated of reinforced galvanized steel or other corrosion-resistant sheet metal, or of plastic.

Flanges at the entering and leaving faces allow the unit to be connected to ductwork. In re-circulating water systems, a float valve maintains proper water level in the reservoir, makes up water that has evaporated, and supplies fresh water for dilution to prevent an overconcentration of solids and minerals. Because the water recirculation rate is low and because high pressure nozzles are not needed to saturate the medium, pumping power is low when compared to spray-filled air washers with equivalent evaporative cooling effectiveness.

4. Method to evaluate evaporative cooling systems

Feasibility index (*FI*) method is a fast method used to verify the viability of using evaporative cooling equipment of air conditioning for human thermal comfort and their application to several cities [7], and is defined by:

$$FI = T_{wb} - \Delta T \quad (1)$$

This index decreases as the difference between dry bulb and wet bulb temperature increases, i.e. as air relative humidity decreases. It shows that, the smaller *FI* is, more efficient the evaporative cooling will be. Thus, this number indicates the evaporative cooling potential to give thermal comfort.

Watt [1] recommend that indices that are under or equal to 10 indicate a comfort cooling, indices between 11 and 16 indicate lenitive cooling (relief) and indices above 16 classify the place as not recommended for use evaporative cooling systems.

From these limits it is possible to conclude that, to reach a comfort recommended performance index, a wet bulb depression from, at least, 12ºC, is needed. It corresponds, e.g. to a DBT of 34ºC with WBT of 22ºC, characterizing a region with relative humidity of approximately 35%. For Bechar city the wet bulb temperature, as can be seen on figure 2, is under or equal to 20°C for the studied months, which means that this city is a well suited site to use the direct evaporative air cooler.

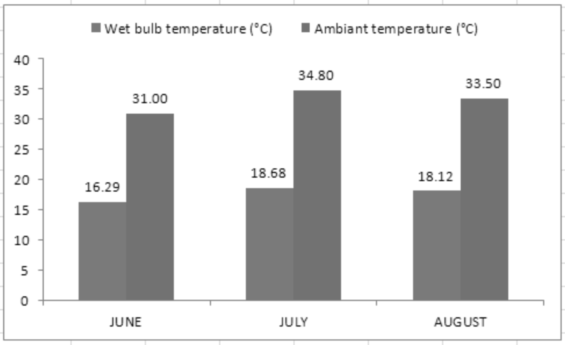

Fig. 2. Monthly wet and dry bulb temperature for the studied months.

5. Theoretical study of direct evaporative air cooler

Evaporative cooling involves heat and mass transfer, which occurs when water and the unsaturated air water mixture of the incoming air are in contact. This transfer is a function of the differences in temperatures and vapor pressures between the air and water. Heat and mass transfer are both operative in the evaporative cooler because heat transfer from the air to the water evaporates water, and the water evaporating into the air constitutes mass transfer. Heat inflow can be described as either latent or sensible heat. Whichever term is used depends on the effect. If the effect is only to raise or lower temperature, it is sensible heat. Latent heat, on the other hand, produces a change of state, e.g., freezing, melting, condensing, or vaporizing. In evaporative cooling, sensible heat from the air is transferred to the water, becoming latent heat as the water evaporates. The water vapor becomes part of the air and carries the latent heat with it. The air dry-bulb temperature (DBT) is decreased because it gives up sensible heat. The air wet-bulb temperature (WBT) is not affected by the absorption of latent heat in the water vapor because the water vapor enters the air at the air wet-bulb temperature. Theoretically, the incoming air and the water in the evaporative cooler may be considered an isolated system. Because no heat is added to or removed from the system, the process of exchanging the sensible heat of the air for latent heat of evaporation from the water is adiabatic. Evaporative cooler performance, therefore, is based on the concept of an adiabatic process [8].

The minimum temperature that can be reached is the wet bulb temperature of the incoming air. Wet pads provide a large water surface in which the air is moistened and the pad is wetted by dripping water. Typical variation of air dry bulb, wet bulb and dew point temperatures through it is illustrated on figure 3.

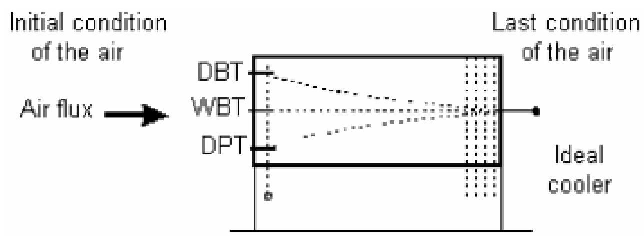

Fig. 3. Typical variation of air dry bulb, wet bulb and dew point temperatures through DEAC [2].

The direct evaporative cooling process works essentially with the conversion of sensible heat in latent heat. The surrounding ambient air is cooled by evaporation of the water from the wet surface of the panel to the air. The addition of water vapor to the air increases its latent heat and relative humidity. If the process is adiabatic, this increase of the latent heat is compensated by a reduction of the sensible heat and consequent reduction of the dry bulb temperature of air. This process is represented on the psychometric chart by a displacement along a constant wet bulb line, AC (figure 4).

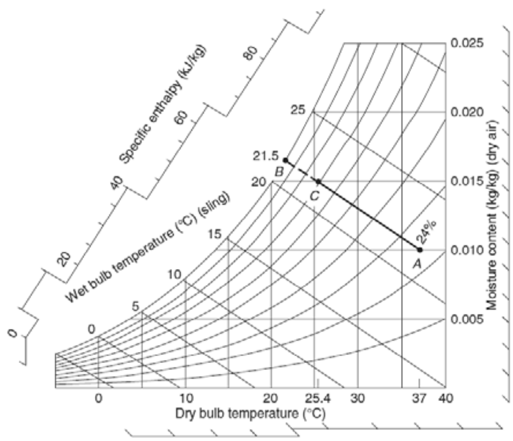

Fig. 4. Direct evaporative cooling process [6]

Direct evaporative panel can basically be considered as a heat exchanger in cross flow [9]. Then, applying an analysis based in classical heat transfer theory, the LMTD method (Log Mean Difference Temperature) can be used.

So, the rate of heat transfer from air to water in the wet panel surface, Q, is given by

$$Q = h\,.A.\ \Delta T_{LM} = m.\ cp.\ (T_2\text{-}T_1) \qquad (2)$$

Where ΔT_{LM} the log mean temperature difference is given by

$$\Delta T_{LM}=\frac{(T_2-T_1)}{ln(T_2-T_{wb})/(T_1-T_{wb})} \quad (3)$$

Substituting equation (3) into equation (2) and regrouping terms follows that,

$$1-\frac{T_1-T_2}{T_1-T_{wb}}=exp\left(-\frac{h.A.(T_1-T_2)}{Q}\right) \quad (4)$$

where the terms $(T_1-T_2)/(T_1-T_{wb})$ is defined as the panel effectiveness ε, i.e.,

$$\varepsilon=\frac{T_1-T_2}{T_1-T_{wb}} \quad (5)$$

From equation (4), the effectiveness of the evaporative panel can also be expressed as

$$\varepsilon=1-exp\left(-\frac{h.A.(T_1-T_2)}{Q}\right) \quad (6)$$

The effectiveness cans be also written as,

$$\varepsilon=1-exp\left(-\frac{h.A}{m.cp}\right) \quad (7)$$

This equation shows that an effectiveness of 100% corresponds to air leaving the equipment at the wet bulb temperature of entrance. This requires a combination of large area of heat transfer and a high heat transfer coefficient and low mass flow. Also, it is observed that the effectiveness is constant if the mass flow is constant, since it controls directly and indirectly the value of the parameters on the equation.

Dowdy and Karabash [10] presented a correlation to determine the convective heat transfer coefficient in a rigid cellulose paper evaporative media:

$$Nu=0.1\,.\left(\frac{L_e}{L}\right)^{0.12}.Re^{0.8}.Pr^{1/3} \quad (8)$$

Where L_e is defined by:

$$L_e=V/A \quad (9)$$

The air temperature leaving the evaporative panel (T_2) can be calculated from equation (5) as,

$$T_2 = T_1 - \varepsilon.(T_1 - T_{wb}) \quad (10)$$

6. Design of an evaporative air cooler

The air change method is used to design an evaporative air cooler. It is based on air change rate (air changes per hour) which is given from codes and standards for specific applications (some common types of rooms and buildings). Note that in many cases local regulations and codes will govern the ventilation requirements.

Once the air change rate is determinate, the air flow rate is calculated from this equation:

$$m = \rho . V . ACR/3600 \tag{11}$$

And water consumption is calculated by this equation:

$$WC = m.(x_2 - x_1) \tag{12}$$

x_1 and x_2 can be taken from psychometric chart.

7. Energy efficiency ratio (EER)

Energy efficiency ratio (EER) was developed by the industry to evaluate the rate of energy consumption for air conditioning units. The energy efficiency ratio is defined as the net thermal energy removed from air for cooling purposes per watt of energy consumed [11]. That is

$$EER = 3.412 . \frac{Q}{W} \tag{13}$$

Where W is the input electrical power of the exhaust fan and water pump.

8. Simulation

Hourly simulation of an evaporative cooler using Thermal Energy System Specialists (TESS) model is done under TRNSYS 16 software [12] for three successive months (June, July and August). The meteorological data of Bechar city for these months are generated by METEONORM [13] software. Typical technical data from AOLAN evaporative air cooler manufacturer data sheet [14] are implemented in the model to predict the performances of this equipment. The effectiveness applied in the model is 0.85%.

9. Results and discussions

Figure 5 shows the monthly average variation of the ambient temperature before and after being passing through the wetted media of the evaporative cooler. The outlet temperature is still around 20°C and the maximum temperature depression reached is 18.86°C for relative humidity from 11 to 74%.

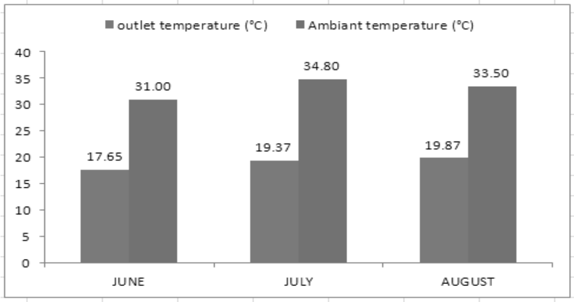

Fig. 5. Monthly average temperature difference between ambient and outlet temperature.

Figure 6 shows the variation of the ambient relative humidity before and after being passing through the wetted media of the evaporative cooler. As we can see, the relative humidity is under 40% and this is under the ASHRAE comfort zone which set the relative humidity between 40 – 60%.

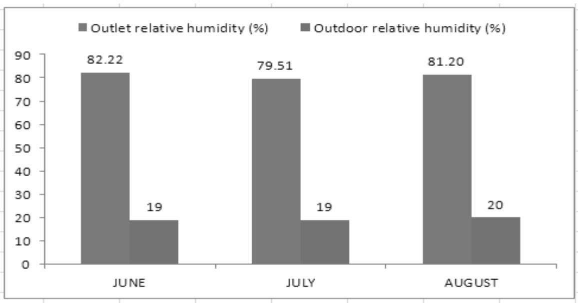

Fig. 6. Monthly average relative humidity before and after cooling

Figure 7 shows the EER and percentage of working hours of the DEAC for the studied months. The EER is calculated for these months in hourly time step. As we can see, the EER is much greater than that of air conditioner units because of the higher air flow rate and lower power consumption of evaporative air cooler systems.

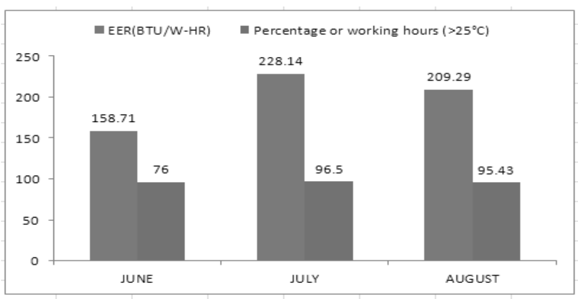

Fig. 7. Monthly average EER and percentage of working hours of the DEAC if the ambient temperature is greater than 25°C.

The hourly average water consumption for these months is about 23 kg/hr. The water consumption is not very excessive but this could be a problem in certain places.

10. Conclusion

This paper presents a simulation and systematic study related to direct evaporative air cooler applied to Bechar city. Also, we present a useful method to evaluate the feasibility of evaporative cooling systems for human thermal comfort. The evaporative cooler is needed in this region because it cool and humidify the ambient air. We conclude that Bechar city is well suited site to the implementation of this technology as well as many others cities whose are under 24°C design wet bulb temperature. Because of their lower power consumption, these systems can be powered by solar photovoltaic panels in regions where there is a lack of electricity or electric network is not available. Evaporative air cooling systems have a very large application potential in Algeria and can be an excellent alternative to the conventional air conditioning systems in hot and dry climates.

References

[1] Watt, J. R. And Brown, W.K, "Evaporative air conditioning handbook", 3rd Edition, the Fairmont Press, Inc., Lilburn, 1997.

[2] G. Heidarinejad et al., "Heat and mass transfer modeling of two stage indirect/direct evaporative air coolers", ASHRAE journal Thailand chapter, 2007-2008.

[3]Washington State University Cooperative Extension Energy Program,WSUCEEP00-302,2003.

[4] Shan k. Wang, "Handbook of air conditioning and refrigeration", Chapter 27, S.E edit. Mcgraw-hill, 2001.

[5]ASHRAE, "Systems and equipment handbook", Chapter 19, 2000.

[6] Santamouris, M. And Asimakopoulos, D.,"Passive cooling of buildings", Publisuhed by James & James (Sciences publishers)Ltd., 2001.

[7] J. R. Camargoa and al, "Three methods to evaluate the use of evaporative cooling for human thermal comfort", (thermal engineering), vol. 5 no 02, 2006, p. 09-15.

[8] R. S. Johnson, "The theory and operation of evaporative coolers for industrial gas turbine installations", Gas Turbine and Aeroengine Congress and Exposition, Amsterdam, 1988.

[9] M. B. Bellorio and al., "Theoretical analysis of air conditioning by evaporative cooling influence on gas turbine cycles performance", 18th International Congress of Mechanical Engineering, Ouro Preto, MG, 2005.

[10] Dowdy, J. A., Karabash, N. S., "Experimental determination of heat and mass transfer co-efficients in rigid impregnated cellulose evaporative media", ASHRAE Trans, Vol. 93, (Part 2), 1987, pp. 382–395.

[11] C. Lertsatitthanakorn and al., "field experiments and economic evaluation of an evaporative cooling system in a silkworm rearing house", Silsoe research institute, 2006.

[12] TRNSYS version 16, "A transient system simulation program", Solar Energy Laboratory, University of Wisconsin, USA, 2005.

[13] METEONORM Version 6.0 by METEOTEST, www.meteonorm.com.

[14] http://www.aolan-china.com/product.aspx