Journal of Engineering Sciences, Assiut University, Vol. 40 , No 5, pp.1351-1358 - September 2012.

CALCULATIONS OF THE OUTLET AIR CONDITIONS IN THE DIRECT EVAPORATIVE COOLER

Waleed A. Abdel-Fadeel[1] and Soubhi A. Hassanein[2]

[1,2] Assistant Professor, Department of Mechanical Engineering, Faculty of Energy Engineering, South Valley University, Aswan, Egypt
[2] Corresponding author. Tel: +20 141480210, Fax: +20 97 3481235,
E-mail address: soubhi_a@yahoo.com, P. O.: 81528 Aswan, Egypt.

(Received March 26, 2012 Accepted June 20, 2012)

ABSTRACT

An equation capable to accurately calculate the wet bulb temperature from the ambient temperature and relative humidity is presented in this paper. Equations for calculation of the outlet air temperature and relative humidity in the direct evaporative cooler are also presented. Direct evaporative cooling is restricted by atmospheric conditions. The outlet air conditions are theoretically determined at different ambient temperatures and relative humidities. Equations for the determination of the outlet air temperature and relative humidity are derived from Psychrometric relations. The equations cover a relative humidity range between 0–100 % and a temperature range between 10–60 ^oC. The influence of the cooling efficiency of the direct evaporative cooler is considered. The equations yield results that agree closely with values given by existing Psychrometric charts.

KEYWORDS: *Temperature; Relative humidity; Evaporative system; Air cooler.*

NOMENCLATURE

E	cooler effectiveness (%)
RH	ambient relative humidity (%)
RH_e	outlet relative humidity (%)
T_a	ambient or dry-bulb temperature (^oC)
T_e	outlet air temperature (^oC)
T_w	wet-bulb temperature (^oC)

1. INTRODUCTION

The direct evaporative coolers have been widely used in many arid areas of the world. They have been used as low energy consuming devices for various cooling and air conditioning applications in industrial, agricultural and residential sectors for providing low temperature fluid (i.e. air, water, etc.). The cooling process occurs due to the high latent heat of vaporization of the water and the difference in temperature between the water and the air. The water absorbs heat from the air and evaporates. The temperature of the air stream decreases while its humidity increases. In the present case, the spray water is entirely recirculated and is neither heated nor cooled, the system is insulated and the make-up water is supplied at wet-bulb temperature. At steady state condition, the evaporative process is an adiabatic humidification cooling process. On a Psychrometric chart, the evaporative process follows a line of constant wet-bulb temperature and it may even reach an extreme value. This value occurs at 100 % relative humidity, where the air leaving the cooler is saturated. Riangvilaikul and Kumar [1] investigated the outlet air conditions and the system effectiveness at different inlet air conditions (temperature, humidity and velocity) covering dry, temperate and humid climates. Ghiabaklou [2] presented the climatic range calculations for comfort evaporative cooling for Tehran. Wu et al. [3,4] developed a simplified mathematical model to describe the heat and moisture transfer between water and air in a direct evaporative cooler. They also theoretically analyzed heat and mass transfer between air and water film. Camargo et al. [5] presented the basic principles of the evaporative cooling process for human thermal comfort, the principles of operation for the direct evaporative cooling system and the mathematical development of the equations of thermal exchanges, allowing the determination of the effectiveness of saturation. Joudi and Mehdi [6] presented hourly-computerized calculations for the variable cooling load using the transfer function method. El-Dessouky et al. [7] investigated a combination that extends the operating range of the evaporative cooler for small differences of dry and wet-bulb temperatures.

Many calculations of Psychrometric properties are made on computers. If any two independent Psychrometric properties of an air-water vapor mixture are known in addition to the atmospheric pressure, the equations can calculate all psychrometric data. In some cases, the direct calculations are difficult and the iteration procedures are necessary. Based on psychometric calculations, Suryawanshi et al. [8] calculated the average output air temperature and relative humidity of the direct and indirect evaporative system. Singh et al. [9] presented equations for calculation of saturation vapour pressure in three different temperature ranges. Oteh [10] presented two equations for use in psychrometric calculations that were derived from the general equation of Parish and Putnam [11]. Oteh and Zachariah [12] presented equations capable to compute the properties of moist air at any prevailing barometric pressure.

2. WET-BULB TEMPERATURE

The calculation of wet-bulb temperature should be accurate as it is used in determining the outlet air temperature at given ambient temperature and cooler effectiveness according to the following equation:

$$E = \frac{T_a - T_e}{T_a - T_w} \times 100 \tag{1}$$

The determination of wet-bulb temperature is somewhat difficult. Hence, there is a need to develop a simple method for the determination of the wet-bulb temperature (Singh et al., [9]).

Parish and Putnam [11] obtained a general expression for relative humidity (RH) as a function of dry-bulb (ambient), wet-bulb temperature and ambient pressure. Their equation at the atmospheric pressure (101.325 KPa) is expressed as:

$$RH = 10^{\left(\frac{2937.4}{T_a+273} - 23.5518\right)} (T_a+273)^{4.9283} \left[10^{\left(\frac{-2937.4}{T_w+273}+23.5518\right)} (T_w+273)^{-4.9283} - 1013.25\,(6.6\times10^{-4} + 7.57\times10^{-7}\,T_w)\,(T_a-T_w)\right] \quad (2)$$

which gives relative humidity as a decimal value.

In case of direct evaporative cooler, the known ambient temperature and relative humidity are essential parts of psychrometric calculations. Therefore, the equation of wet-bulb temperature should be a function of them, i.e. :

$$T_w = f\,(T_a\,, RH) \quad (3)$$

A general expression for wet-bulb temperature as a function of dry-bulb temperature and relative humidity is assumed to be a parabolic equation as follows:

$$T_w = C_1\,RH^2 + C_2\,RH + C_3 \quad (4)$$

The constants C_1, C_2 and C_3 are functions of T_a and are suggested to be expressed as :

$$C_i = A_i T_a^{n_i} + B_i \quad (5)$$

Therefore, the suggested equation can be expressed as :

$$T_w = (A_1 T_a^{n_1} + B_1)\,RH^2 + (A_2 T_a^{n_2} + B_2)RH + (A_3 T_a^{n_3} + B_3) \quad (6)$$

The values of the constants A_i, B_i and n_i are found. Substituting the constants into Eq. (6) yields the following equation of the wet-bulb temperature.

$$T_w = (-2.21\times10^{-6}\,T_a^{1.724} + 7.87\times10^{-5})\,RH^2 + (9.58\times10^{-4}\,T_a^{1.549} + 6.91\times10^{-2})RH + 1.5924\,T_a^{0.727} - 7.843 \quad (7)$$

Figure 1 shows a comparison between values given by the present equation (7) and those given by Parish and Putnam, Eq. (2). The present equation (7) calculates the wet-bulb temperature as a function of relative humidity for the ambient temperatures range of 10-60 ^{o}C that covers all the expected operating temperatures of the direct evaporative cooler. The equation yields results that agrees closely with values given by Eq. (2). As shown in the figure, the maximum deviation is being -0.57 ^{o}C for ambient temperature of 10 ^{o}C and relative humidity of 100 %, -0.13 ^{o}C for (20 ^{o}C, 2.5 %), 0.45 C for (30 ^{o}C, 100 %), 0.62 ^{o}C for (40 ^{o}C, 100 %), -0.63 C for (50 ^{o}C and 2.3 %) and -0.96 C for (60 ^{o}C, 2.6 %).

3. OUTLET AIR TEMPERATURE

Once the equation of the wet-bulb temperature as a function of ambient temperature and relative humidity has been defined, equation of outlet air temperature can be obtained by substituting Eq. (1) into Eq. (7) as follows:

$$T_e = T_a(1-E) + E[(-2.21\times10^{-6}\,T_a^{1.724} + 7.87\times10^{-5})RH^2 + (9.58\times10^{-4}\,T_a^{1.549} + 6.91\times10^{-2})RH + 1.5924\,T_a^{0.727} - 7.843] \quad (8)$$

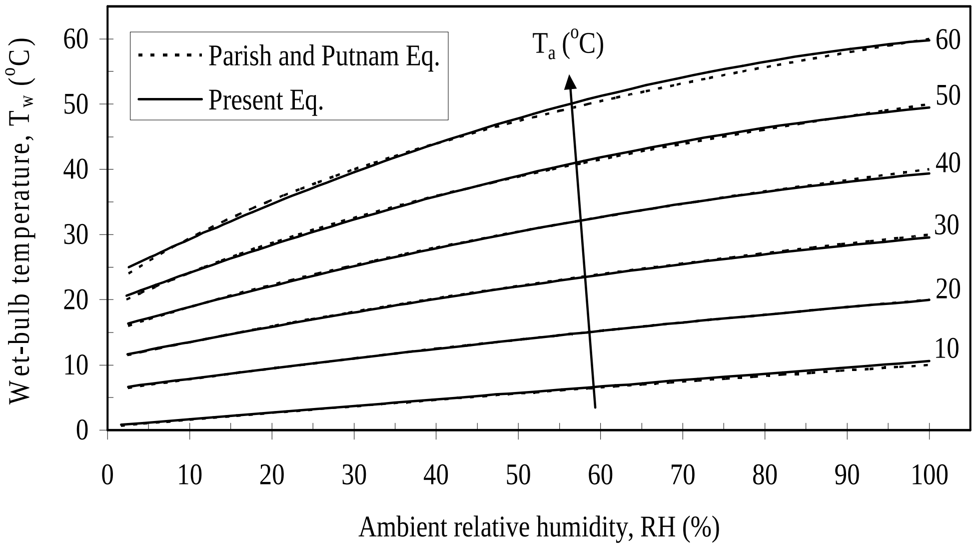

Fig. 1 Comparison between the present equation and Parish and Putnam equation.

Figure 2 shows an example of the values of the outlet air temperature given by the present equation (8) for different inlet air conditions and cooler effectiveness of 75 %. The results cover a relative humidity range between 0–100 % and a temperature range between 10–60 °C. The outlet air temperature was found to be linearly dependent on the ambient temperature at constant relative humidity. For relative humidity of 100 %, the outlet temperature was the same as the ambient temperature.

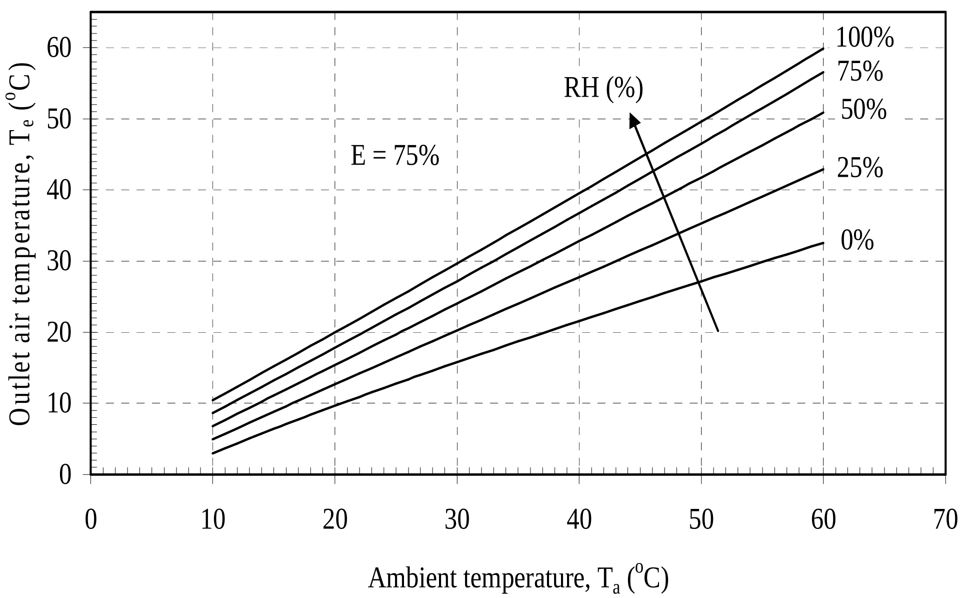

Fig. 2 Outlet air temperature at 75% effectiveness.

Figure 3 shows another example of the values of the outlet air temperature given by the present equation (8) for different inlet air conditions and relative humidity of 50 %. The results cover a cooler effectiveness range between 0–100 % and a temperature range between 10–60 °C. The outlet air temperature was found to be linearly dependent on the ambient temperature at constant cooler effectiveness. As sown in the figure, for cooler effectiveness of 0 %, the outlet temperature was the same as ambient temperature. This means that the Equation (8) works well.

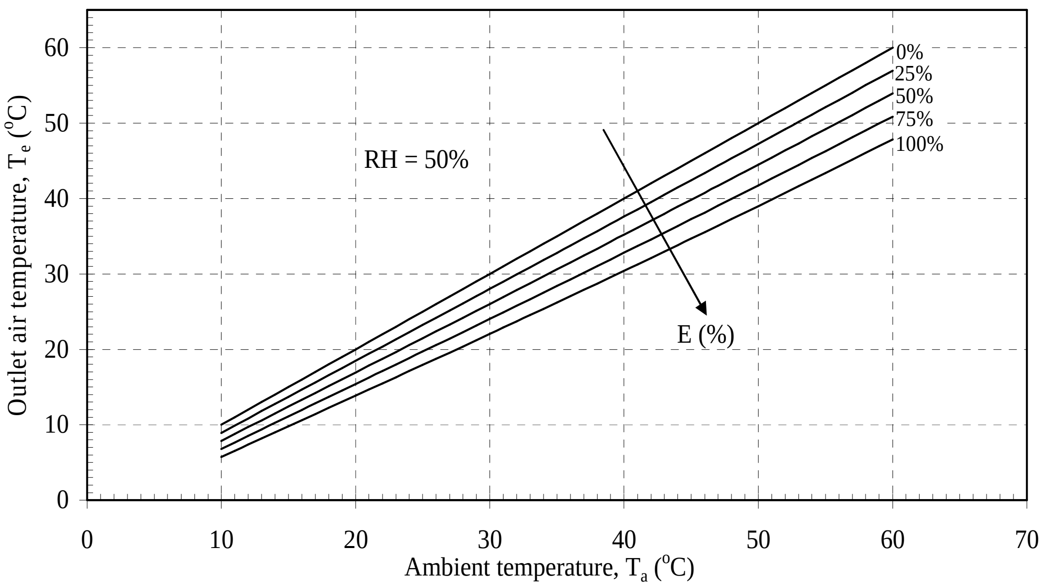

Fig. 3 Outlet air temperature at 50% ambient relative humidity for different cooler effectiveness values.

4. OUTLET RELATIVE HUMIDITY

The moisture content of the air increases which results in an increase in relative humidity along a line of constant wet bulb temperature or enthalpy. The outlet relative humidity can be calculated by using Parish and Putnam equation (2) and replacing the value of ambient temperature (T_a) by that of the outlet air temperature calculated from equation (8).

Figure 4 shows an example of the values of the outlet relative humidity for different inlet air conditions and cooler effectiveness of 75 %. The results cover a relative humidity range between 0–100 % and a temperature range between 10–60 °C. The outlet air temperature was found to be almost linearly dependent on the ambient temperature at constant relative humidity. The accuracy of the calculated values of outlet relative humidity depends on the ambient temperature and relative humidity. For relative humidity of 100 %, the accurate values of the outlet relative humidity must be 100 %, the maximum deviation being 1.7 % for ambient temperature of 10 °C.

Figure 5 shows the values of the outlet relative humidity for different inlet air conditions and relative humidity of 50 %. The results cover a cooler effectiveness range between 0–100 % and a temperature range between 10–60 °C. The outlet relative humidity was found to be almost linearly and parallel dependent on the ambient temperature at constant cooler effectiveness. For relative humidity of 100 %, the accurate values of the outlet relative humidity are achieved. For relative humidity of 0 %, a maximum deviation is being 1.31 % for ambient temperature of 10 ^oC and 1.06 % for 60 ^oC

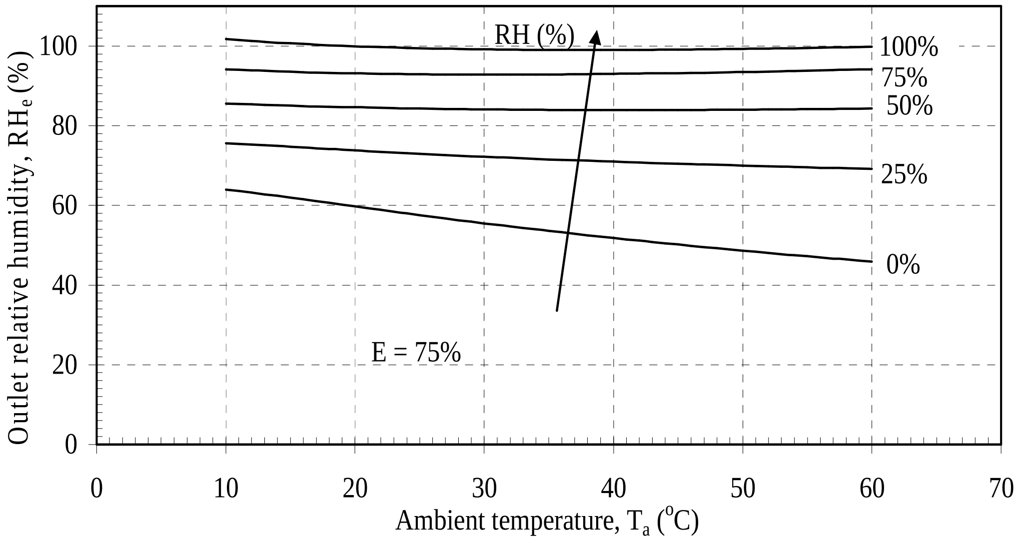

Fig. 4 Outlet relative humidity at 75% effectiveness for different ambient relatives humidity values.

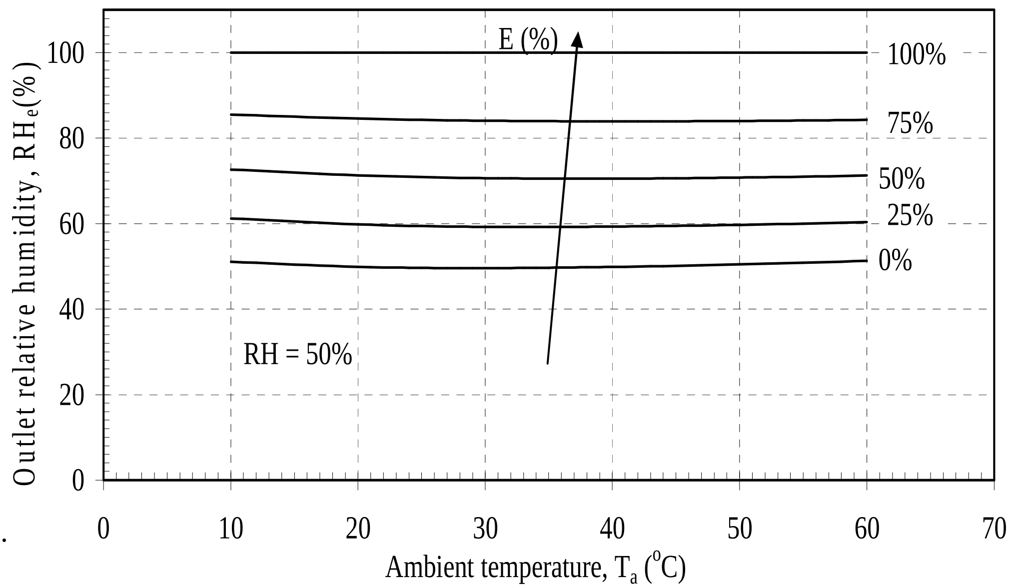

Fig. 5 Outlet relative humidity at 50% ambient relative humidity and different effectiveness values.

5. CONCLUSION

This study succeeded to derive an equation capable to accurately compute the wet bulb temperature from the ambient temperature and relative humidity. The outlet air condition (temperature and relative humidity) from the direct evaporative cooler are also calculated directly at different air conditions and cooler effectiveness. The relationships proposed here cover a relative humidity range between 0–100 % and a temperature range between 10–60 ^{o}C.

REFERENCES

[1] Riangvilaikul, B. and Kumar, S., 2010, An experimental study of a novel dew point evaporative cooling system, Energy and Buildings 42: 637–644.

[2] Ghiabaklou, Z., 2010, Climatic range for comfort evaporative cooling, World Academy of Science, Engineering and Technology 68: 931-934.

[3] Wu, J.M., Huang, X. and Zhang, H., 2009, Numerical investigation on the heat and mass transfer in a direct evaporative cooler, Applied Thermal Engineering 29: 195–201.

[4] Wu, J.M., Huang, X. and Zhang, H., 2009, Theoretical analysis on heat and mass transfer in a direct evaporative cooler, Applied Thermal Engineering 29: 980–984.

[5] Camargo, J.R., Ebinuma, C.D. and Silveira, J.L., 2005, Experimental performance of a direct evaporative cooler operating during summer in a Brazilian city, International Journal of Refrigeration 28: 1124–1132.

[6] Joudi, K.A. and Mehdi, S.M., 2000, Application of indirect evaporative cooling to variable Socidomestic cooling load, Energy Conversion & Management 41: 1931-1951.

[7] El-Dessouky, H.T., Ettouney, H.M. and Bouhamra, W., 2000, A novel air conditioning system, Membrane air drying and evaporative cooling, Trans IChemE 78(A): 999-1008.

[8] Suryawanshi, S.D., Chordia, T.M., Nenwani, N., Bawaskar, H. and Yambal, S., 2011, Efficient technique of air-conditioning, Proceedings of the World Congress on Engineering Vol III, London, U. K., 2036-2041.

[9] Singh, A.K., Singh, H., Singh, S.P. and Sawhney, R.L., 2002, Numerical calculation of psychrometric properties on a calculator, Building and Environment 37: 415-419.

[10] Oteh, U.U., 1985, Equations for psychrometric calculations, International Journal of Refrigeration 8: 116-117.

[11] Parish, O. O. and Putnam, T. W., 1977, Equations for determination of humidity from dewpoint and Psychrometric data, National Aeronautics and Space Administration, NASA,

[12] Oteh, U.U. and Zachariah, K.P., 1985, Psychrometry, a microcomputer, International Journal of Refrigeration 8: 246-248.

[13] ASHRAE, 2001, Psychrometrics in: Handbook of fundamentals (SI). American ety of Heating, Refrigerating and Air-Conditioning Engineers, pp. 6.1-6.17.

حساب درجة حرارة ورطوبة الهواء المنبعث من المبرد التبخيرى

قدم هذا البحث معادلة رياضية جديدة قادرة على حساب درجة حرارة الهواء الرطب بمعلومية كل من درجة حرارة الهواء الجاف والرطوبة النسبية. تم استخدام هذه المعادلة لحساب درجة حرارة ورطوبة الهواء المنبعث من المبرد التبخيرى. ويمكن استخدام هذه المعادلات على نطاق واسع حيث أنها صالحة للتطبيق من درجة حرارة 10 إلى 60 درجة مئوية، وكذلك من رطوبة نسبية 0 إلى 100 % وهذه القيم تمثل الغالبية العظمى لاستخدامات المبرد التبخيرى. كما تم أخذ كفاءة المبرد التبخيرى في الاعتبار داخل المعادلة. وقد حققت المعادلة نتائجا دقيقة بالمقارنة مع خرائط التبريد والتكييف.