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Empirical Model to Calculate the Thermodynamic Wet-Bulb Temperature of Moist Air

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Abstract

An equation model for calculating the adiabatic temperature of the wet-bulb thermometer has been obtained empirical fit through a meteorological database, specificly a trough relative humidity and air temperature. A comparison of the results of calculations with the use of this equation and from meteorological database was made. The model deducted of the comparison is valid for a dry bulb temperature range of 3˚C to 35˚C and for relative humidity percentage in a range of 7% to 97%. Normalized errors are less than 5.5%. It means a maximum variation of 0.55˚C from data. However, this variation from error represents only 3.6% of the data sample. The equation model was satisfactory.

Keywords

Wet-Bulb Temperature Equation, Dry-Bulb Temperature, Relative Humidity, Dry Solar Technologies, Humidified Gas Turbines

1. Introduction

The condensation and vaporization processes are important in different conventional and non-conventional systems of energy, using fossil fuel or renewable energies, and in systems applied to refrigeration, evaporation, air conditioning, humidification, condensation, dehumidification and airing. For example, as in [1] it shows a complete abstract about refrigeration for evaporation under different climate characteristics, and efficiency of several evaporative cooling equipments is indicated, through wet and dry bulb, and its relationship with mass and heat

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transference processes. These processes can be carried out using solar energy, through the use of different technologies as in [2]. In the industry of electrical production, they have application in the cogeneration systems, throughout compressed air to feed a gas turbine, and in cooling systems of incoming air to the turbines which allows output power increase, and improves thermal efficiency; these efficiencies are obtained through local climate conditions. The calculations began with determination of temperature of wet bulb ambient as in [3]. Also, they have application in the different gas turbine cycles as water injection cycles, steam injection cycles and evaporative cycles with humidification [4] [5]. Design and analysis of all these systems require knowledge of properties corresponding to dry air and steam water mixture from local environment. Calculus methodology of those properties from dry bulb temperature (T_{db}), relative humidity (ϕ), local altitude (Z) is known and is shown by ASHRAE [6]. However, to determine thermodynamic wet bulb temperature(T_{wb}), according to the methodology, a numerical implementation is necessary [7]-[11].

In the present work, an equation to determine wet bulb temperature for mentioned conditions, is presented. It was obtained by processing numerical data of a Meteorological Station located in the region Ciénega of Chapala in Michoacán México, with latitude 20˚0'52.24"N and length 102˚44.37'37.11"W. During the numerical analysis 91,519 data were processed, for each of the variables involved, and they correspond to a typical local year.

2. Methodology

The considered variables for the analysis were dry bulb temperature and relative humidity, in ranges from 3˚C to 35˚C, and 7% to 97% respectively, with local altitude Z = 1526 m [12]. Wet bulb temperature was determined considering data equation and according to methodology described by ASHRAE, throughout a numerical implementation. Data were grouped as a function of relative humidity; the ranges consisted of 5 units, as it can be seen in **Figure 1**.

For each humidity range T_{wb} vs T_{db} were plotted and a linear adjusted equation was obtained, with general form: $T_{wb} = AT_{db} + B$. **Table 1** shows adjustment equations for each humidity range and the coefficients of determination.

Then, coefficients for A and B were correlated, for each humidity range considered (average of the range) as shown in **Figure 2**. Thus, Equation (1) was obtained and polynomial for coefficients A and B.

$$T_{wb} = \sum_{i=0}^{3} A_i(\phi) T_{db} + \sum_{i=0}^{4} B_i(\phi) \quad (1)$$

In Equation (1), relative humidity is considered dimensionless, with T_{db} and T_{wb} given in ˚C. Adjusted coefficient values for each polynomial, are shown in **Table 2**.

3. Results and Discussion

Equation (1) has in its general form a linear behavior for dry bulb temperature. But coefficients A_i and B_i de-

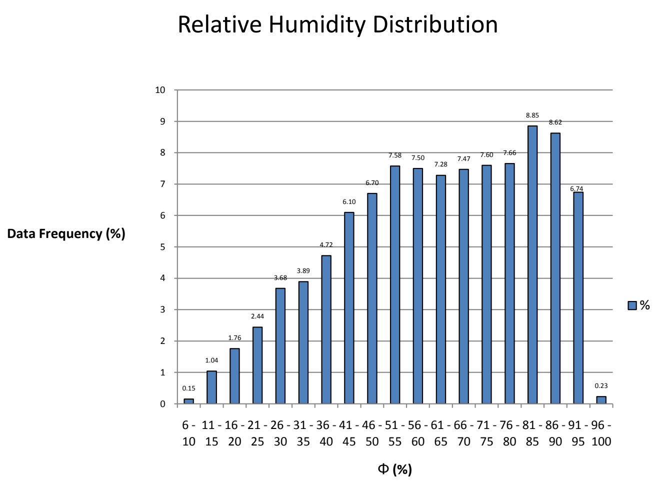

Figure 1. Percentage distribution for humidity ranges.

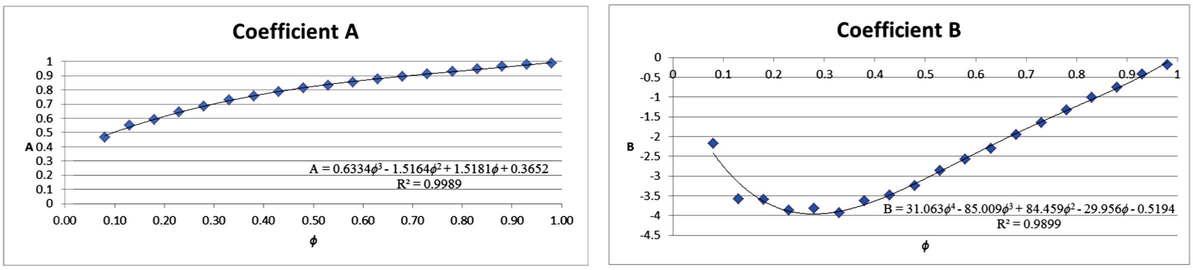

Figure 2. Polynomial coefficients for A and B with coefficients of determination.

Table 1. Adjustment equations from T_{wb} and T_{db} for each interval humidity.

Φ	Equation	R^2
6 - 10	$T_{wb} = 0.4658T_{db} - 2.177$	0.8672
11 - 15	$T_{wb} = 0.5506T_{db} - 3.5846$	0.8711
16 - 20	$T_{wb} = 0.593T_{db} - 3.5889$	0.9144
21 -25	$T_{wb} = 0.6456T_{db} - 3.8737$	0.9643
26 - 30	$T_{wb} = 0.6845T_{db} - 3.8201$	0.9828
31 - 35	$T_{wb} = 0.7277T_{db} - 3.9253$	0.9868
36 - 40	$T_{wb} = 0.7555T_{db} - 3.6281$	0.9915
41 - 45	$T_{wb} = 0.7876T_{db} - 3.4778$	0.9935
46 - 50	$T_{wb} = 0.814T_{db} - 3.2415$	0.9944
51 - 55	$T_{wb} = 0.8329T_{db} - 2.8555$	0.9957
56 - 60	$T_{wb} = 0.8547T_{db} - 2.5688$	0.9965
61 - 65	$T_{wb} = 0.8772T_{db} - 2.3067$	0.9971
66 - 70	$T_{wb} = 0.8951T_{db} - 1.9578$	0.9973
71 - 75	$T_{wb} = 0.9127T_{db} - 1.6419$	0.9974
76 - 80	$T_{wb} = 0.9293T_{db} - 1.327$	0.9979
81 - 85	$T_{wb} = 0.9464T_{db} - 1.0134$	0.998
86 - 90	$T_{wb} = 0.9642T_{db} - 0.7506$	0.998
91 - 95	$T_{wb} = 0.9772T_{db} - 0.4249$	0.9967
96 - 100	$T_{wb} = 0.9852T_{db} - 0.1798$	0.9999

Table 2. Fit coefficients for proposal equation.

Coefficient	Value
A_0	0.3652
A_1	1.5181
A_2	1.5164
A_3	0.6334
B_0	−0.5194
B_1	−29.956
B_2	84.459
B_3	−85.009
B_4	31.063

pend on relative humidity, and they are 3th and 4th degree polynomials.

Figure 3 shows the correlation of T_{db}, ϕ, T_{wb} for data station and it is compared with the obtained values from Equation (1), for mentioned ranges, with acceptable fit.

In order to evaluate Equation (1), two errors are estimated: normalized error (E_n) and real error (E_r). These are obtained from base data and with calculated data, according to the proposed equation. Normalized error evaluation was obtained using the following equation: $E_n = \left[\left(T_{wb,DB} - T_{wb,ThisWork}\right)/T_{wb,DB}\right]100\%$. And real error using equation: $E_r = T_{wb,DB} - T_{wb,ThisWork}$.

Figure 4 shows the error between the proposed model and wet bulb temperature data from the meteorological station. The maximum normalized error is 5.4% (secondary vertical axis, E_n) and is equivalent to maximum variation of 0.6˚C as shown in the main vertical axis (E_r). Absolute average error is 0.065% (En_av) about meteorological station, representing an average variation of a hundredth degree Celsius from real error (Er_av = 0.011˚C).

Also, **Figure 4** shows that normalized error is present in a range of −6 and 3, and to estimate how this error impacts in base data, absolute frequencies were settled, from normalized error.

Table 3 shows absolute frequencies, this is to estimate the data quality from normalized error. This table shows an E_n range (X_j) according to **Figure 4**. Absolute frequency is determined by data selection and it is clear that between 1.0 and −1.0 a percentage of 96.4 of the obtained data are present.

Figure 5 shows data from **Table 1** plotted, and 88,265 data are between 1.0 and −1.0, which indicates that the

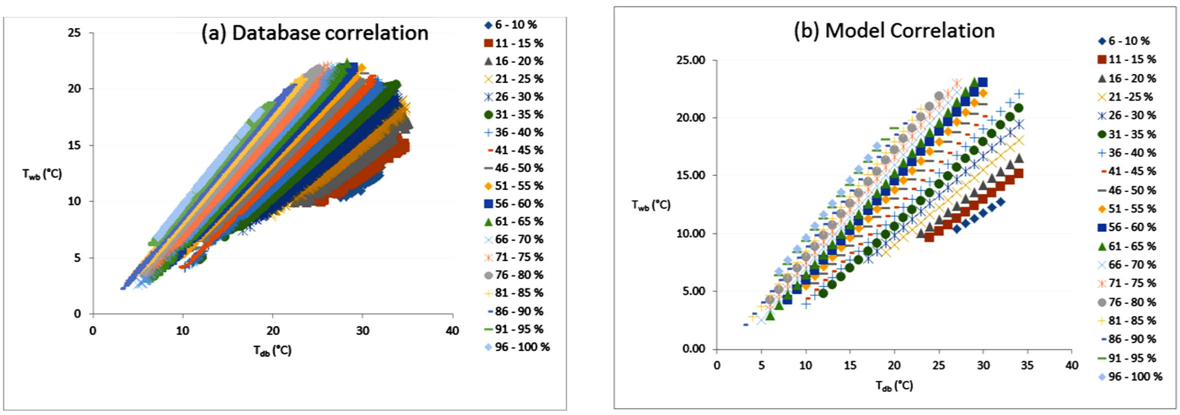

Figure 3. Comparison of T_{db}, ϕ, T_{wb} correlation of meteorological data (a); and from proposed model according to **Table 1(b)**.

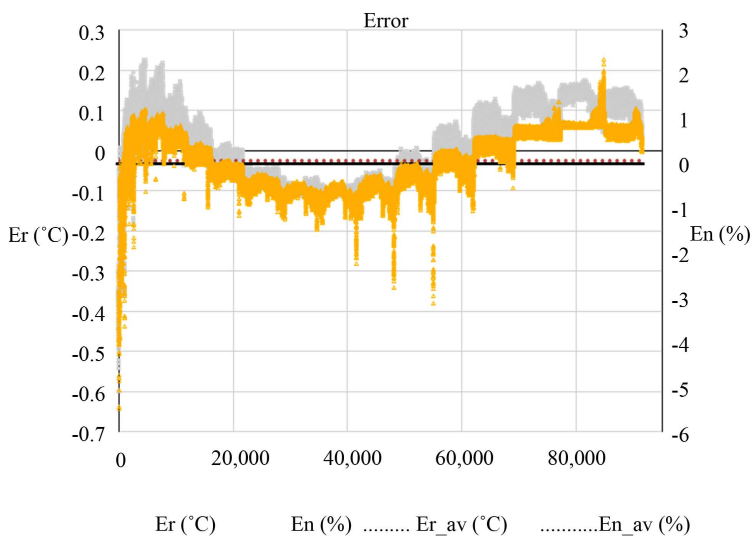

Figure 4. Comparison between real error and normalized error evaluated with data from meteorological station.

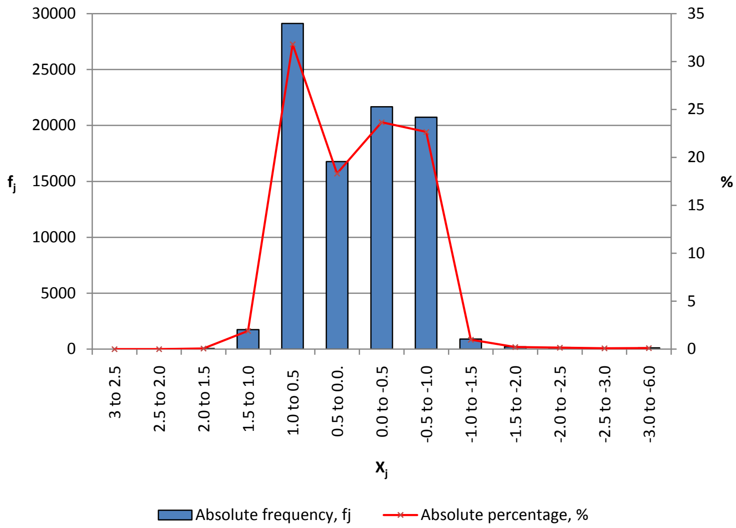

Figure 5. X_j vs f_j corresponding to data shown in **Table 2**.

Table 3. Absolute frequency with its corresponding percentage to E_n data.

X_j	Absolute frequency, f_j	Absolute percentage, %
3 to 2.5	0	0
2.5 to 2.0	5	0.0054
2.0 to 1.5	65	0.071
1.5 to 1.0	1735	1.89
1.0 to 0.5	29,115	31.81
0.5 to 0.0.	16,757	18.3
0.0 to −0.5	21,663	23.67
−0.5 to −1.0	20,730	22.66
−1.0 to −1.5	908	0.99
−1.5 to −2.0	201	0.22
−2.0 to −2.5	143	0.16
−2.5 to −3.0	79	0.086
−3.0 to −6.0	110	0.12
	DB = 91,519	99.98

difference of real error and normalized error are in an acceptable value (only 3.6% of total data are out of 1.0 and −1.0).

4. Conclusion

A direct equation was obtained in order to predict wet bulb temperature, from relative humidity and dry bulb temperature. Methodology used to obtain the model, was in an empiric way, grouping relative humidity in ranges of 5 units, and for each range wet and dry bulb temperatures were correlated, obtaining a general linear adjust. Also, coefficients A and B were evaluated. Quality of generated data for the model was settled through error analysis. Normalized errors are less than 5.5%. It means a maximum variation of 0.55˚C from data. The normalized error applies only to 3.6% of the data considered in the present work. The model has an acceptable fit. It is valid for a range of temperature and relative humidity of 3˚C to 100˚C and 7% to 97% respectively. The pressure was calculated from the local altitude and the model behavior was not explored at different pressures. The equation obtained represents an important tool that facilitates the analysis and engineering calculations of various important energy processes.

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Nomenclature

A, B	Fit Coefficients
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
E_n	Normalized Error, %
En_av	Absolute Normalized Average Error
E_r	Real Error, ˚C
Er_av	Real Average Error
f_j	Absolute Frequency
N	North
W	West
R^2	Coefficient of Determination
T	Temperature, ˚C
X_j	Range, Corresponding to E_n Values.
Z	Local Altitude, m
Φ	Relative humidity, %
ϕ	Relative Humidity, Dimensionless
Subscript	
db	Dry bulb
DB	Database
i	Component *i*-th of fit Coefficients
j	Data from E_n
n	Normalized
r	Real
wb	Wet bulb