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Analysis of Ambient Dry Bulb Temperature and Relative Humidity Data of Ikeja, Nigeria for Refrigeration and Air-Conditioning

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Abstract: ***Data of 15 years for dry bulb temperature and relative humidity were available. The data were recorded on hourly basis, using the Greenwich Mean Time (G.M.T) as the standard of time. Hourly averages and standard deviation were computed for all the 24 hours of the day. Average daily range, of dry bulb temperature and relative humidity were computed for all the months in the year. Models were developed for the diurnal variation of dry bulb temperature and relative humidity. Values predicted with these models were compared with values computed from measured hourly data and the agreements are quite good. Olorunmaiye et al (2015) in a recent study confirmed that the agreement between the models developed in the present study and those developed using the data of 1995 to 2008 was very good. Negative values of cross-correlation coefficients were recorded throughout for all the months for the 15-year period. Statistical estimates were made for 5%, 2.5% and 1% design values of dry bulb temperature. Estimates were also made from the actual distribution of ambient dry bulb temperature. Statistical estimates were also made for 5%, 2.5% and 1% design values of ambient relative humidity. From the analysis, it was established that maximum cooling design temperature does not occur in July in Ikeja, which is contrary to Carrier's assumption.***

Keywords: Models, Dry bulb Temperature, Relative Humidity, Average Daily Range, Standard Deviation

1. Introduction

The environmental requirements, which are accepted as adequate for human activities as well, as for their well being, are called thermal comfort. Knowledge of the air temperature is necessary because it is the most important of the four weather variables that determine thermal comfort. Differences between the ambient temperature Ta, and the air temperature inside a building, result in heat conduction through the shell of the building. In structures of building of general use, changes of temperature of outer surface results in periodical temperature change inside the structure which produces a peak temperature travelling from outside to the inside of the building (Gutkowski, 1996). The peak temperature inside the wall may be higher than the outdoor temperature. This can be observed in the evening and at nighttime when the temperature difference between night and day is large.

The performance of cooling plant is based on design temperatures, which are chosen on a statistical basis, bearing in mind the nature of the climate and the response of the building. The rate of heat loss or gain through the building shell by conduction is a simple function of the magnitude of the temperature difference and the thermal resistance of the building shell. Ambient temperature is not constant, therefore heat transfer varies and steady conditions are never reached.

Infiltration, which is the flow of ambient air into a building through openings in the shell of the building, may also account for appreciable portion of the cooling load requirement of a building. Infiltration is caused by air density difference between room and outdoor air, which results in air exchange. Some mass of room air is exchanged with warm outdoor air. A measure of the amount of water vapour present in the air is known as humidity. Water vapour present in the air varies from place to place at different times of the day. The actual amount of water vapour that air can hold varies with the temperature, the warmer the air the more water it can hold. There is a limit to the amount of water vapour a given quantity of air can hold, which depends on its temperature. When the air has reached this limit, it is said to be saturated (Erbs, 1984; Ariyo, 1997; ASHRAE, 2013).

Changes in atmospheric humidity affect thermal comfort. Humidity within a building is often maintained within a range to avoid discomfort. Moisture gains can be produced by ventilation, infiltration of outdoor air and drying of some items inside the room. Water vapour is removed from the air in the process of cooling the air to provide temperature control. Latent heat caused by infiltration of outdoor air is reflected in heat gain due to infiltration. Although the mass flow rate of water vapour which infiltrates is small, the high latent heat of vaporisation of water can cause the energy required for control in humid climate to become a significant fraction of the total cooling load (Erbs,1984)

Shoboyejo and Shonubi (1974) recommended outdoor design conditions for various cities in Nigeria from their statistical analysis of hourly dry bulb temperature 3-hourly wet bulb temperature and vapour pressure data for 15years (1951 – 1965). Assuming the distribution of dry bulb temperature is normal, they used statistical tables to find 1%, 2.5% and 5% normal probability confidence values. Normal distribution is a convenient assumption since statistical tables can be used with ease if the mean and standard deviation are available. The distribution of dry bulb temperature is not normal but useful design values can be obtained using the assumption of normal distribution.

Carrier Corporation (1997) made assumptions for cooling load calculations for places in the Northern and Southern Hemisphere. Nigeria is in the Northern Hemisphere and no particular attention was given to cities in Nigeria regarding the months in which maximum and minimum cooling loads occur respectively.

2. Theoretical Development

Fourier series was used in developing models for dry bulb temperature and relative humidity. In this work, the explicit nature of y = f (θ), where θ is time of the day, is not known, therefore numerical Fourier analysis was employed. The diurnal variation curve for each month was standardized by subtracting the monthly– average daily dry bulb temperature or relative humidity from the monthly–average hourly dry bulb temperature, or relative humidity for each hour of the day and dividing the resulting differences by the peak-to-peak amplitude for that curve. Fourier series was fitted to each of the average curve for Ikeja.

For dry bulb temperature,

$$(\overline{T}_{a,h} - \overline{T}_a)/A = -0.4647\cos(t^*-0.5463) +0.1548\cos(2t^*-0.4402) +0.0126\cos(3t^*-1.5358) -0.0305\cos(4t^*-0.7149) \quad (1)$$

Where A is the amplitude of the diurnal variation (peak-to-peak), of ambient temperature.

For relative humidity,

$$(\overline{RH}_h - \overline{RH})/A = +0.4888\cos(t^*-0.5521) -0.1609\cos(2t^*-0.6454) +0.0146\cos(3t^*+1.2246) +0.0339\cos(4t^*-1.2897) \quad (2)$$

Where A is the amplitude of the diurnal variation (peak-to-peak), of relative humidity.
t* in both equations (1) and (2) is given by
$t^* = 2\pi t/24$

t =0,1,2,----------------------,23 (G.M.T) (3)

Cross–correlation coefficient, which is a measure of the dependence of the two variables, dry bulb temperature and relative humidity, was computed from the hourly data of the variables, on monthly basis. The cross-correlation coefficient $\rho_{Ta\text{-}Rh}$ is defined by

$$\rho_{Ta\text{-}Rh} = \frac{\sum_{i=1}^{n} (T_{ai} - \overline{T}_a)(RH_i - \overline{RH})}{\sqrt{\sum_{i=1}^{n} (T_{ai} - \overline{T}_a)^2 \; \Sigma(RH_i - \overline{RH})^2}} \quad (4)$$

Where T_a and RH are hourly dry bulb temperature and relative humidity respectively, $\overline{T}_a$ and $\overline{RH}$ are the monthly averages.

The distribution of ambient temperature and relative humidity for Ikeja can be expressed by Gaussian or normal statistical density function,

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-1/2((x-\overline{x})/\sigma)^2] \quad (5)$$

Where x is the value of the random variable (ambient temperature or relative humidity), x and σ are the mean and standard deviation respectively and are given as follows:

$$\overline{x} = 1/n \sum_{i=1}^{n} x_i \quad (6)$$

$$\sigma = \sqrt{\sum_{i=1}^{n} (x_i - \overline{x})^2/n} \quad (7)$$

i = 1,2,3,.......................,n.
The values of x_p for given values of P% are evaluated using probability tables.

3. Analysis of Data

Hourly ambient dry bulb temperature and relative humidity data for Ikeja (latitude 6° 40'N, longitude 3° 20' E) for 15 years (1978-1992) were collected in printed format from Nigerian Meteorological Services, Oshodi, Lagos for the computer analyses. Hourly averages, standard deviations and average daily ranges of dry bulb temperatures and relative humidity for Ikeja were computed from measured hourly data of dry bulb temperature and relative humidity. Tables 1 and 2 show the monthly average daily temperatures and relative humidity, standard deviation and average daily ranges for Ikeja. Equations (1) and (2) were used to predict values of dry bulb temperatures and relative humidity. The values predicted were compared with those computed directly from the measured data. Figures 1 and 2 show the standardized diurnal variation of monthly average hourly dry bulb temperature and relative humidity for Ikeja.

Cross-correlation coefficients were computed from the measured data. Cross-correlation coefficient is a measure of the dependence of dry bulb temperature and relative humidity. Negative values of cross-correlation coefficient were recorded throughout for the 15-year period. The implication of this is that greater than average values of hourly dry bulb temperature occurred at the same time as less than average values of hourly relative humidity and vice-versa. Table 3 shows cross-correlation coefficients between hourly dry bulb temperature and relative humidity for Ikeja. Generally cross-correlation coefficient, ρ lies between -1 and +1. Since ρ is nearly -1 for Ikeja, the implication of this is that there is a high degree of statistical dependence between dry bulb temperature and relative humidity.

Table 1: Monthly Average Daily Dry Bulb Temperatures, Standard Deviation and Average Daily Range for 15 Years (1978-1992) for Ikeja (^oC)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Average	26.9	28.2	28.5	28.3	27.3	25.9	24.8	24.9	25.2	26.0	27.0	26.7
Standard Deviation	2.9	2.7	2.4	2.3	2.0	1.6	1.5	1.6	1.9	2.0	2.4	2.7
Av. Daily Range	8.6	8.0	7.0	6.5	5.6	4.5	4.0	4.1	4.6	5.5	6.7	7.9

Table 2: Monthly Average Daily Relative Humidity, Standard Deviation and Average Daily Range for 15 Years (1978-1992) for Ikeja (%)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Average	76.3	77.7	79.8	81.1	84.6	87.8	88.3	87.2	87.8	86.6	84.3	80.6
Standard Deviation	14.0	13.8	11.8	10.8	8.6	6.7	6.7	7.5	7.2	8.3	10.1	12.7
Av. Daily Range	37.8	37.3	32.3	29.3	23.3	17.8	17.3	19.2	19.1	22.0	27.5	34.8

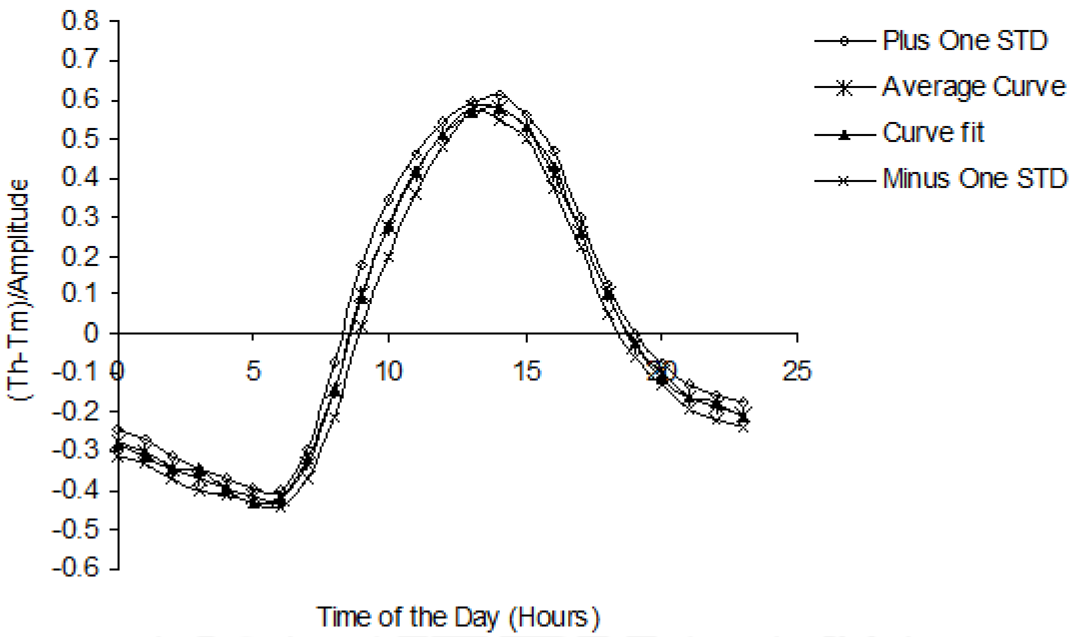

Figure 1: Standarised Diumal Variation of Monthly Average Hourly Dry Bulb Temperature for Ikeja

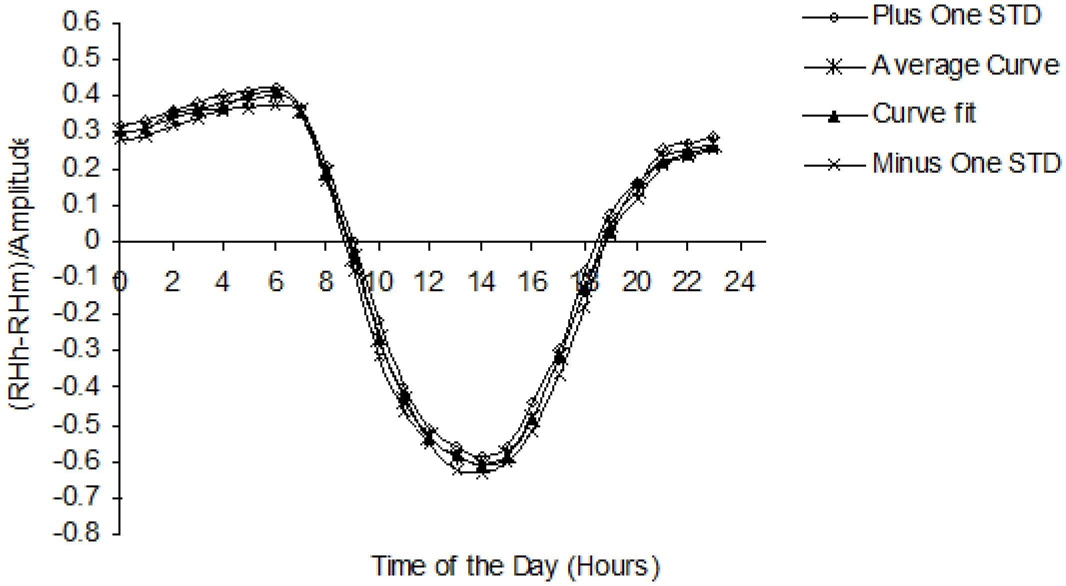

Figure 2: Standarised Diumal Variation of Monthly Average Hourly Relative Humidity for Ikeja

Table 3: Cross-Correlation Coefficients between Variations of Dry Bulb Temperature and Relative Humidity from their Respective Monthly-Average Values for Ikeja. X means Data not Available

Year	!978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
Jan	-0.76	X	-0.94	-0.89	-0.50	-0.59	-0.71	-0.81	-0.72	-0.90	-0.67	-0.62	-0.96	-0.53	-0.47	-0.72
Feb	-0.94	-0.96	-0.92	-0.87	-0.70	-0.72	-0.55	-0.92	-0.92	-0.96	-0.67	-0.62	-0.82	-0.94	-0.88	-0.83
Mar	-0.93	-0.92	-0.95	-0.88	-0.89	-0.93	X	-0.94	-0.92	-0.92	-0.91	-0.91	-0.96	-0.93	-0.90	-0.92
Apr	-0.93	-0.93	-0.91	-0.92	-0.94	-0.91	X	X	-0.94	-0.92	X	-0.94	-0.91	-0.93	-0.92	-0.93
May	-0.90	-0.84	X	X	-0.92	-0.91	X	-0.92	-0.90	-0.91	X	-0.94	-0.92	-0.92	-0.93	-0.91
Jun	-0.91	-0.91	-0.91	-0.92	-0.85	-0.85	X	-0.91	-0.90	-0.95	-0.92	-0.91	-0.94	-0.90	-0.89	-0.91
Jul	-0.92	-0.93	-0.88	-0.89	-0.86	-0.93	X	-0.90	-0.90	-0.93	-0.92	-0.93	X	X	-0.95	-0.91
Aug	-0.95	-0.90	-0.88	-0.92	-0.94	-0.92	X	-0.95	-0.94	-0.90	-0.95	-0.91	-0.96	-0.94	-0.95	-0.93
Sep	-0.94	-0.89	-0.90	-0.93	-0.94	-0.94	X	-0.94	-0.92	-0.91	-0.92	-0.95	-0.93	-0.92	-0.95	-0.93
Oct	-0.94	-0.90	-0.90	-0.93	-0.93	-0.95	X	-0.92	-0.94	-0.94	-0.93	-0.92	-0.91	-0.94	-0.96	-0.93
Nov	-0.83	-0.89	-0.93	-0.79	-0.87	-0.95	-0.94	-0.94	-0.96	-0.97	-0.93	-0.96	-0.94	-0.96	-0.77	-0.91
Dec	-0.96	-0.83	-0.44	-0.94	-0.83	-0.88	-0.72	X	-0.58	-0.73	-0.39	-0.86	-0.82	-0.67	-0.85	-0.75

Statistical estimates were made for 95%, 97.5% and 99% normal probability confidence values of dry bulb temperature for Ikeja. Estimates were also made from the actual distribution of ambient dry bulb temperature. The differences are less than 1°C. The design month is defined as the month with the highest mean maximum temperature for the four warmest months of the year. The average daily range is defined as the difference between the average maximum and the average minimum temperatures during the design month. The four warmest months for Ikeja from this study are February, March, April and May. The design data for 99%, 97.5% and 95% confidence values for dry bulb temperatures are the maximum hourly outside temperature which have been equalled or exceeded for 1%, 2.5% and 5% of the total hours of the four warmest months. Table 4 shows the design dry bulb temperature obtained using normal statistical table and earlier work by Shoboyejo and Shonubi (1974).

Table 4: Design Dry Bulb Temperatures Obtained Using Normal Statistical Table for the Four Warmest Months

(a) Present Work

City	Elevation (m)	Design Month	Outdoor Daily Range(°C)	Design Dry Bulb Temperature (°C) 1%	2.5%	5%	Mean	Standard Deviation (°C)
Ikeja	39.3	March	7.0	33.7	32.8	32.0	28.1	2.4

(b) Shoboyejo and Shonubi (1974)

City	Elevation (m)	Design Month	Outdoor Daily Range(°C)	Design Dry Bulb Temperature (°C) 1%	2.5%	5%	Mean	Standard Deviation (°C)
Ikeja	39.3	March	9.4	31.7	30.6	30.0	25.6	2.8

Statistical estimates were made for 95%, 97.5% and 99% normal probability confidence values of relative humidity for Ikeja. Estimates were also made for the actual (cumulative) distribution of relative humidity. The design data for 99% 97.5% and 95% confidence values for relative humidity are the maximum hourly outside relative humidity, which have been equalled or exceeded for 1%, 2.5% and 5% of the total hours of the four warmest months. The 1% and 2.5% design relative humidity obtained using normal distribution statistical tables exceeded 100%. This shows that the distribution of relative humidity cannot be approximated by normal distribution. Indeed Erbs (1984) assumed Weibull distribution for relative humidity. Because the design values obtained using normal distribution statistical tables were not reasonable, results are not presented using this method. The design relative humidity values obtained from cumulative distribution curve are shown in table 5.

Table 5: Design Relative Humidity Obtained from Cumulative Distribution Curves for the Four Warmest Months

City	Elevation (m)	Design Month	Outdoor Daily Range (%)	Design Relative Humidity (%) 1%	2.5%	5%	Mean	Standard Deviation (%)
Ikeja	39.3	March	32.3	96.3	94.8	93.8	80.8	11.5

Carrier corporation assumed for Northern latitude that monthly dry bulb temperature values vary sinusoidally with the time during the year and highest monthly maximum occurs in July while the minimum occurs in January. The monthly maximum dry bulb temperatures are the one percent design temperature values for all the months in the year. Carrier also assumed that average hourly dry bulb temperature profile for each month is sinusoidal with maximum occurring at 3.p.m (G.M.T) and minimum at 3. a.m.(G.M.T). Figures 3 and 4 show the one percent cooling design temperatures and relative humidity on monthly basis for Ikeja.

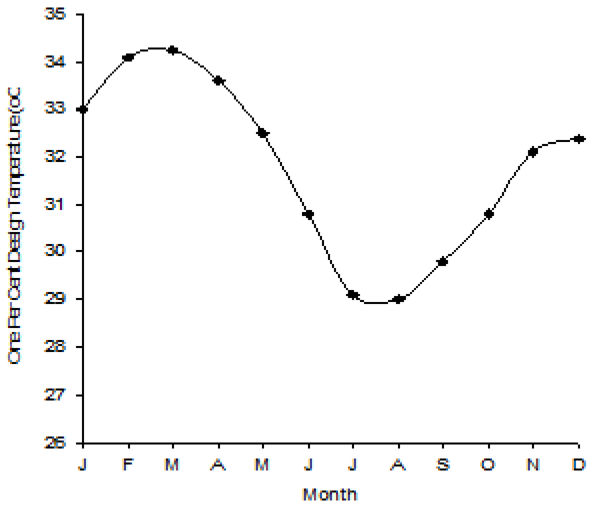

Figure 3: One Per cent Design Temperature for the Twelve Months for Ikeja

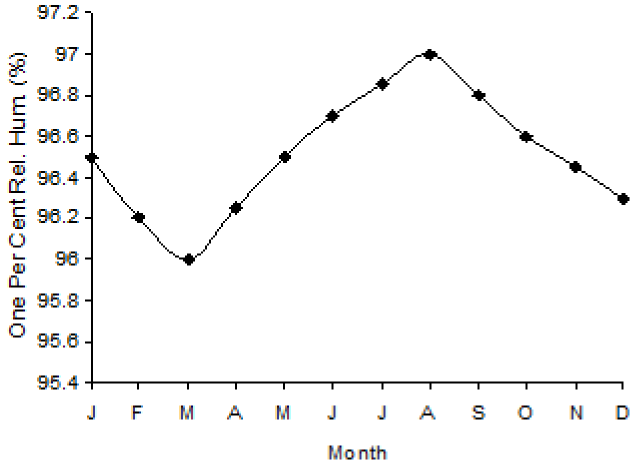

Figure 4: One Per cent Design Relative Humidity for the Twelve Months for Ikeja

4. Discussion of Results

Figures 1 and 2 show the standardized diurnal variation of dry bulb temperature and relative humidity for Ikeja. The diurnal variation of relative humidity is as a result of diurnal variation of dry bulb temperature and it follows a cyclic variation throughout the day because the diurnal variation is cyclic. The dry bulb temperatures at Ikeja are greatly influenced by the presence of the Atlantic Ocean. This is as a result of air masses travelling across the Ocean, which can either dissipate heat or gain heat from the water. Figures 3 and 4 show the one percent cooling design temperatures and relative humidity respectively on monthly basis for Ikeja. Although Carrier Corporation mentioned that the assumptions made may not be appropriate for all sites in the world, monthly maximum dry bulb temperatures do not vary sinusoidally with time during the year as assumed by Carrier. Also the maximum and minimum cooling design temperatures do not occur in July and January. It was indeed discovered that maximum cooling design temperature does not occur in July in Ikeja when using Carrier E-20 programmes for cooling load calculation for Ikeja (Olorunmaiye, 1996). The maximum and minimum cooling design temperatures for Ikeja occur in March and August respectively. The assumption of Carrier Corporation may be good for places in the upper latitudes of the North, it is not appropriate for countries like Nigeria in the lower latitudes of the Northern Hemisphere. Although the variation of the average hourly dry bulb temperature profile for Ikeja is cyclic, the assumption of sinusoidal variation does not agree with Figure 3. Also the assumption of maximum and minimum temperatures occurring at 3 p.m. (G.M.T) and 3 a.m. (G.M.T) does not agree with the average hourly dry bulb temperature profile for Ikeja. The outside design dry bulb temperature values computed using normal probability distribution statistical tables and those obtained from the cumulative distribution of dry bulb temperature are close. The differences are less than 1^{o} C for 1%, 2.5% and 5%design dry bulb temperature for Ikeja. The values obtained from cumulative distribution curves are generally higher than those obtained from statistical tables because the actual distribution of ambient temperature is not normal. The results obtained in this work are generally higher than those of Shoboyejo and Shonubi (1974). This may be as a result of global warming. The data used by Shoboyejo and Shonubi(1974) covered 1951-1965 while the data used in this work covered 1978-1992.

A strong statistical dependence exists between dry bulb temperature and relative humidity. Negative correlation coefficient were recorded throughout, which shows that greater than average values of hourly dry bulb temperature occurred at the same time as less than average values of hourly relative humidity and vice-versa. These are shown in Figures 1 and 2 and Table 3.

5. Conclusions

The models developed in this work were compared with the measured data, which they represent. The mathematical forms for the models are as simple as possible and accurately represent the measured data. Olorunmaiye et al (2015) in a recent study confirmed that the agreement between the models developed in the present study and those developed using the data of 1995 to 2008 was very good.

The present work is more recent than that of Shoboyejo and Shonubi (1974), hence the design dry bulb temperatures obtained give more current picture of the external design conditions than those of Shoboyejo and Shonubi (1974).

The assumptions of Carrier Corporation for maximum and minimum cooling design temperatures for Ikeja are not correct, therefore cooling design temperatures obtained in this work will give accurate results in cooling load calculations.

References

[1] **Ariyo, D.O.** (1997). Models for ambient dry-bulb temperature and relative humidity statistics related to building cooling load for Ilorin and Ikeja. M.Eng. Project Report, Department of Mechanical Engineering, University of Ilorin.

[2] ASHRAE (2013). Handbook of fundamentals., S.I. Edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

[3] **Carrier corporation**, (1997). Weather Data Guide. E2O-II, Carrier International Corporation. New York.

[4] **Erbs, D.G.** (1984). Models and applications for weather statistic related to building heating and cooling loads. Ph.D Thesis. Department of Mechanical Engineering, University of Wisconsin-Madison.
[5] **Gutkowski, K.M.** (1996). Refrigeration and air-conditioning. Spectrum books Limited, Ibadan.
[6] **Olorunmaiye, J.**A. (1996). Personal Communication.
[7] **Olorunmaiye, J.A.**, Ariyo, D.O., Awolola, O.O., Omolehin, I.S. (2015). Models of dry-bulb temperature and relative Humidity for Ilorin and Ikeja Suitable For Engineering Applications. Journal of Engineering Research, Volume 20 No.1 March 2015
[8] **Shoboyejo, A.B.O., and Shonubi, F.A.**(1974). Evaluation of outside design conditions for air-conditioning system design in Nigeria. The Nigerian Engineer, Volume 9, No1, January - March, pp 5 – 11.