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Climate Change and Its Implication on Energy Consumption for Refrigeration Systems (Ilorin as a Case Study)

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Abstract
The ambient air temperature and relative humidity data recorded hourly by Nigerian Meteorological Agency (NIMET), at the Ilorin International Airport for the period 1995 to 2009 were obtained at Nigerian Meteorological Agency (NIMET), Oshodi. These data were keyed into computer using Microsoft Excel package. The hourly mean dry bulb temperature for each month was calculated, the minimum and the maximum of the hourly mean were determined and the difference of these were computed for each month as the range for the month. The standard deviation for each month was also computed. The bin data were developed for both hourly dry bulb temperature and relative humidity for Ilorin. The results show that the lowest monthly mean dry bulb temperature occur in August and was found to be 24.53°C, and the highest monthly mean dry bulb temperature was found to be 29.44°C in March. The modal dry bulb temperature bin was 23-24°C. Dry bulb temperature which falls below 24°C occurs for an average of 2481.16 hours which is 28.30% of the total number of hours for the whole year of which August has a total of 257.20 hours. Comparison of bin data for dry-bulb temperature and relative humidity for the period 1995 – 2009 with results obtained for an earlier period (1978 – 1992) showed evidence of climate change. The month of March has highest hours of relatively hot weather and refrigerators will expend more energy. The month of August has the highest number of lower temperature and less energy will be expended on refrigeration. It is therefore recommended that there should be regular review of the analyses done in this work for subsequent periods to monitor climate change and its implication for energy consumption in refrigeration systems.

Keywords: Dry bulb temperature, relative humidity, refrigeration, energy.

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1. INTRODUCTION

The process of heat removal from a space which results in either decrease in temperature or keeping the temperature constant is termed refrigeration (Gutkowski, 1996).This process can be achieved in a natural way by utilizing a medium at a temperature lower than temperature of the substance to be cooled or by artificial method -mechanical process in which a working substance in a closed thermodynamic cycle produces low temperature. The dry bulb temperature in a refrigerator should be between 3 – 5°C if food stored in it is to be well preserved without loss of nutrients, where as the ideal freezer temperature is -18°C to store food safely and stop bacteria forming (Knowhow.com, 2015). Dry bulb temperature is an important climate variable relevant to refrigeration. The performance of certain types of equipment used in refrigeration and air conditioning systems is a function of ambient temperature, for example, the ability to reject heat for an air cooled condenser of vapour compression refrigeration unit reduces with increasing ambient temperature (Olorunmaiye and Ariyo, 1998).

Ilorin is in the North Central geopolitical Zone of Nigeria. It is situated in the geographical coordinates of 8° 26'N, 4° 29' E and about 306 km from the coastal city of Lagos and 500 km from Abuja in the federal capital territory. It is centrally located between the forests zone of the South West and the savannah region of the North. Ilorin has annual rainfall range of 1000mm to 1500mm (NSE, 2012). The months of December and January fall within the cold and dry harmattan period. Several studies have been carried out on the climatic condition of Ilorin.Shoboyejo and Shonubi (1974) reported that the month with the highest mean temperature was March based on the meteorological data of 1951-1965. Ariyo (1997) developed models for ambient temperature and relative humidity of Ilorin and Ikeja. His work was based on the Meteorological data of 1978-1992.

2. RELATED LITERATURE

Saidur et al (2005) worked on the factors that affect the energy consumption of refrigerator-freezer. He identified three independent variables, namely: ambient temperature, load in refrigerator-freezer, and the number of times the refrigerator door is opened per hour. He found that among these variables, change in ambient temperature had the strongest effect on energy consumption of the refrigerator-freezer. A report on climate change prepared by California Energy Commission declared that with the increase in ambient temperature, substantial building energy usage is anticipated. A work by Huang (2006) reported that energy use for space cooling in Los Angeles will increase by as much as 42 percent in residential buildings and 31 percent in commercial buildings, while heating will go down by 62 percent and 24 percent, respectively toward the end of this century. Electricity used for cooling will increase and gas for heating will decrease. The net energy use will increase by 25 percent to 28 percent by 2100, (Peng et al, 2009).

The effect of climate change on energy consumption for cooling systems in Tehran was studied using a 40 year long term measured temperature. It was reported that increase in dry bulb temperature has great influence on the performance of cooling devices. As a result of this, it was concluded that the rate of additional energy for vapour absorption and compression systems will grow more and more in the future. (Delfania et al, 2010) In their work on the simulation of impact of climate change on energy consumption in building, Roshan et al (2012) concluded that with warm seasons prolonging and cold seasons shrinking in a year, the need for the continuous supply of energy consumption for air cooling and ventilation increases.

In a study of the effect of ambient air temperature on the energy consumption of a refrigerator, Olorunmaiye et al (2012) considered three temperature conditions and they concluded that the higher the ambient air temperature of the space that houses the refrigerator, the higher the power consumption by the refrigerator. Olorunmaiye and Awolola (2015) presented the work done on statistical analysis of dry-bulb temperature for Ilorin and its implication on energy consumption for refrigerators. The change in weather conditions over the years has been of great concern to many people in the world. This is as a result of increase of the earth surface temperature which poses a problem of energy utilisation in a way to reduce the effect of climate change or global warming. What effect has global warming had on energy utilisation? Therefore the analysis of weather records could be of a great help to see how the temperature is distributed through the year.

The main objective of the work presented in this paper is to enrich the work reported by Olorunmaiye and Awolola (2015) by including statistical analysis of relative humidity and compare the results of both statistical analyses of dry-bulb temperature and relative humidity with those obtained for an earlier period. Inferences will be drawn from the results on climate change and how energy required to power refrigeration systems is affected.

3. MATERIALS AND METHODS

The data for this research work is the 15 years hourly dry bulb temperature of Ilorin for 1995 to 2009 obtained from Nigerian Meteorological Agency office, NIMET, off Kappa Bus Stop, Oshodi, Nigeria. These data were stored monthly on excel file worksheets. There were twelve (12) worksheets created one for each month of the year. The following statistical analyses were carried out;

i. Average otherwise known as arithmetic mean defined as the sum of n numbers divided by the total number n.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

Where $\bar{x}$ = mean, x_i = variable, and n = the number of variables

ii. Standard deviation which is a measure of variability based on all the data in a set. These are obtained as square root of variance:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (2)$$

Where σ = standard deviation, $\bar{x}$ = mean, x_i = variable, and n = the number of variables

iii. Minimum is the lowest value out of a given set of variables. In this work the minimum hourly average dry bulb temperature for each month was determined.

iv. Maximum is the highest value out of a given set of variables. In this work, the highest hourly average dry bulb temperature for each month was determined.

v. Range is the difference between the maximum and minimum of the hourly average dry bulb temperature.

vi. The bin data of the hourly dry bulb temperature was compiled. The temperature range was divided into bins of 1°C width. The number of hours that temperature recorded falls into a bin divided by the number of hours in the year is the probability of occurrence for that bin.

These analyses were carried out on the hourly average dry bulb temperature using Microsoft Excel.

4. RESULTS AND DISCUSSIONS

Table 1 shows the average dry bulb temperature, standard deviation, minimum, maximum temperature and range for each month for the 15-year period. The bin data for each month of the year is presented in Table 2. The Relative Humidity bin data for Ilorin for the period 1995-2009 is in Table 3. The average number of hours per annum at Ilorin in which the dry-bulb temperature is less than or equal 24°C in the present work based on 1995 – 2009 data along with the results obtained by Olorunmaiye and Ariyo (1998) based on 1978 – 1992 data are shown in Table 4. Table 5 shows the average number of hours in which dry-bulb temperature is greater than 24°C for the same sets of data.

Figure 1 is a bar chart showing the dry-bulb temperature bin data for both 1978 – 1992 and 1995 – 2009 sets of data. Figure 2 is the corresponding bar chart for the relative humidity data.

Table 1: Monthly Mean Dry Bulb Temperature, Standard Deviation, Minimum, Maximum And Range For Ilorin (°C)

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	26.85	28.73	29.44	28.44	27.09	25.77	24.94	24.53	25.01	25.85	27.05	26.74
STD	4.93	4.74	4.35	3.74	3.36	2.94	2.47	2.24	2.74	3.16	4.21	4.91
Min	20.71	22.73	24.27	24.39	23.70	22.75	22.47	22.14	28.78	22.53	22.22	20.71
Max	33.87	35.47	35.66	33.53	31.42	29.58	28.19	25.59	22.23	30.33	33.31	33.86
Range	13.16	12.74	11.39	9.15	7.72	6.78	5.71	5.45	6.50	7.80	11.09	13.15

Table 2: Ambient Air Temperature Bin Data For Ilorin (Hours)

T_{DB} (°C)	MONTHS											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12-13	0	0	0	0	0	0	0	0	0	0	0	0.28
13-14	0	0	0	0	0	0	0	0	0	0	0	0.28
14-15	0.41	0	0	0	0	0	0	0	0.07	0	0.21	0.97
15-16	2.07	0	0	0	0	0	0	0	0	0	0.41	3.25
16-17	3.31	0.07	0	0	0	0	0	0	0	0	1.31	8.29
17-18	9.92	0.55	0	0	0	0	0	0	0	0	2.75	11.54
18-19	19.9	3.99	0.28	0	0	0.07	0.22	0.07	0	0.14	7.08	19.63
19-20	25.61	9.9	0.35	0	0	0.22	0.81	0.15	0.3	0.41	8.73	21.29
20-21	33.74	13.41	3.29	0.47	3.5	10.76	7.9	9.16	17.5	6.67	14.51	24.12
21-22	34.57	18.09	7.15	5.61	16	30.27	38.77	45.64	49.33	38.79	21.87	29.79
22-23	40.83	24.9	17.51	23.59	47.07	77.31	118.08	152.42	116.01	92.84	48.14	42.02
23-24	55.98	34.39	31.67	41.64	70	111.74	149.02	149.76	130.93	120.62	79.15	59.79
24-25	59.91	52	49.6	64.7	93	106	102.2	96.74	84.18	95.93	88.78	70.5
25-26	56.26	63.76	79.58	89.43	93.79	76.1	78.2	79.38	66.54	67.46	65.81	61.38
26-27	46.2	53.58	78.95	83.08	73.86	57.23	66.54	71.19	56.57	52.88	47.93	45.9
27-28	42	45.67	59.06	59.82	56	52.93	60.11	61.59	59.74	52.33	44.77	42.99
28-29	41.38	43.26	49.53	52.47	55.07	56.23	57.53	48.74	51.62	51.3	39.13	37.32
29-30	37.46	34.87	43.29	46.85	51.07	55.58	43.35	22.89	47.63	51.09	36.17	34.49
30-31	41.59	37.97	40.63	47.86	52.57	50.28	17.87	5.02	28.36	51.03	40.5	36.22
31-32	37.46	31.78	38.32	45.32	54.64	26.39	3.25	1.11	9.38	39.34	41.05	40.78
32-33	47.3	40.03	38.6	48.06	42.14	6.67	0.07	0.07	1.77	16.3	46.56	44.44
33-34	45.79	35.91	40.35	44.52	21.86	1.58	0	0	0	5.5	43.67	47.69
34-35	35.25	44.78	47.71	32.02	9.29	0.43	0	0	0.07	1.24	29.91	41.96
35-36	16.18	45.05	51.21	18.58	3.36	0.07	0	0.07	0	0.07	9.63	16.8
36-37	8.81	30.54	44.35	9.83	0.43	0.07	0	0	0	0	1.58	2
37-38	1.72	10.25	18.78	5.15	0.07	0	0	0	0	0	0.21	0.14
38-39	0.21	2.48	3.64	1	0.21	0.07	0	0	0	0	0.07	0.07
39-40	0.14	0.76	0.14	0	0.07	0	0.07	0	0	0	0.07	0.07
40-41	0	0	0	0	0	0	0	0	0	0.07	0	0

Table 3: Relative Humidity Bin Data For Ilorin For The Period 1995-2009

RH %	MONTHS											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5-10	0.90	0.89	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
10-15	12.33	22.15	7.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	2.07
15-20	39.04	48.15	15.27	0.13	0.00	0.00	0.00	0.00	0.00	0.00	2.48	13.48
20-25	54.53	55.16	22.98	0.40	0.00	0.00	0.00	0.00	0.00	0.28	11.21	32.49
25-30	65.90	66.24	28.37	1.47	0.14	0.00	0.00	0.00	0.00	0.55	23.66	49.49
30-35	72.23	64.59	38.18	4.75	0.36	0.00	0.00	0.07	0.00	1.72	34.25	56.95
35-40	68.65	57.37	49.46	8.15	0.93	0.07	0.00	0.00	0.07	2.54	38.65	62.41
40-45	59.49	42.78	47.43	18.78	3.93	0.29	0.00	0.00	0.00	3.23	41.67	57.09
45-50	55.57	33.36	49.81	37.50	8.93	0.72	0.00	0.00	0.22	6.26	38.65	56.82
50-55	43.59	26.34	44.21	50.20	22.57	3.80	0.59	0.15	1.77	10.66	41.19	52.05
55-60	38.28	25.73	43.86	55.68	45.07	19.94	5.61	2.44	7.90	30.05	41.95	47.55
60-65	34.02	25.17	44.00	58.02	69.21	53.22	30.42	16.17	30.35	50.06	45.32	44.24
65-70	32.02	25.52	42.73	55.81	67.43	68.92	59.22	45.42	61.74	63.54	48.14	39.40
70-75	27.75	27.65	51.21	58.22	63.50	66.77	76.43	75.47	71.34	61.62	47.66	38.08
75-80	26.03	29.78	54.92	64.17	63.79	58.31	63.21	74.51	60.70	58.93	45.59	33.66
80-85	27.34	41.06	82.67	87.63	79.43	70.72	79.16	85.51	65.21	66.50	51.16	34.63
85-90	32.84	44.43	78.25	101.53	97.29	86.42	92.16	96.59	77.46	76.95	57.56	38.36
90-95	37.73	34.12	35.94	80.41	131.79	155.49	175.31	179.82	136.76	132.45	78.95	49.49
95-100	14.94	7.29	5.74	34.16	79.64	121.92	136.39	152.20	177.16	157.20	64.23	29.51
100-105	0.83	0.21	0.35	3.01	10.00	13.41	25.48	15.66	29.32	21.46	7.50	6.15

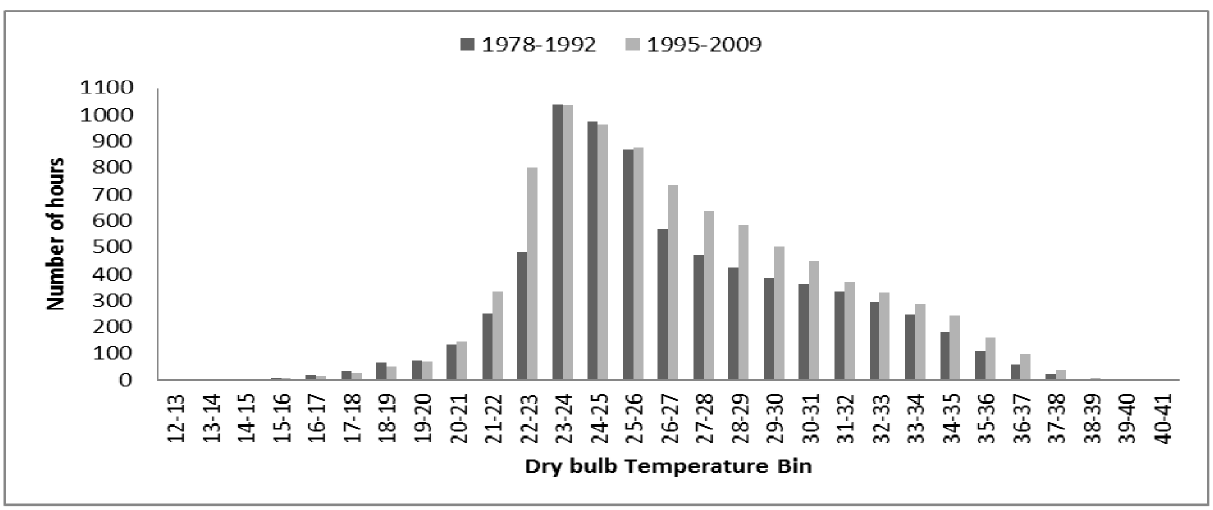

Figure 1: Comparison Of 1978-1992 And 1995-2009 Dry Bulb Temperatures Bins

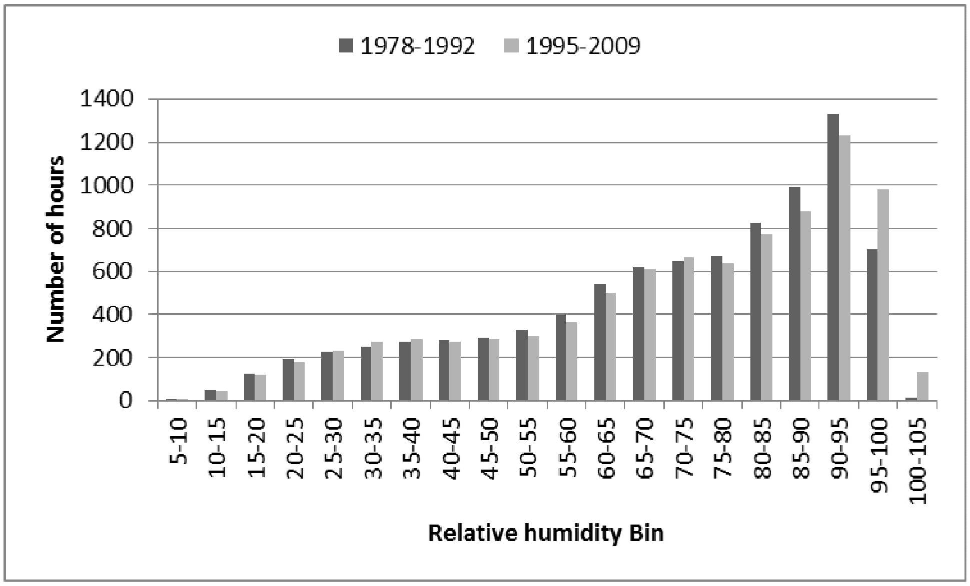

Figure 2: Comparison Of 1978-1992 And 1995-2009 Relative Humidity Bins

Table 4: Number Of Hours In Which Dry Bulb Temperature Is Less Than Or Equal To 24°c Based On 1995 – 2009 Data Compared With Results From 1978 – 1992 Data.

MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC
1995 – 2009	226.34	105.30	60.25	71.31	136.57	230.37	314.8	357.2	314.14	259.47	184.16	221.25
1978 – 1992	250.6	106.7	64.8	85.3	149.5	226.3	363.8	386.5	353.8	290.6	200.8	269.1

Table 5: Number Of Hours In Which Dry Bulb Temperature Is Above 24°c Based On 1995 – 2009 Data Compared With Results From 1978 – 1992 Data.

MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC
1995 – 2009	517.66	572.69	683.74	648.69	607.43	489.63	429.19	386.80	405.86	484.54	535.84	522.75
1978 – 1992	488.4	571.0	679.1	634.7	597.7	493.5	380.3	357.5	366.2	453.4	519.2	475.1

From the results presented in Table 1, March has the highest average dry bulb temperature of 29.44°C followed by February with 28.73°C, while August has the lowest dry bulb temperature of 24.53°C. The implication of these is that energy consumption of refrigeration systems would be highest in March than any other month of the year. It was reported by Saidur et al (2005) that the highest contributory factor to higher energy consumption of refrigerator is ambient temperature of the space where it is operated. This was also confirmed by Olorunmaiye et al (2012). August will experience lowest energy consumption by refrigeration systems. The month of January has the highest range which shows that the diurnal variation is higher in January than any other month. August has the lowest diurnal dry bulb temperature variation.

Table 2 shows that the minimum dry bulb temperature bin is 12-13°C which occurs only in a few Decembers (average of 0.28 hours per year). This is higher than the number of hours in this temperature bin (12-13°C) which was0.167 hours per year for 1978-1992 data. This shows that more hours have temperature in that range in this 1995-2009 data. The lowest dry bulb temperature for January occur in 14-15°C with 0.41 hours which is at variance with the result of 1978-1992 data where the lowest temperature occur in 12-13°C bin for an average of 0.357 hours per year. The highest dry bulb temperature occur in the of 40-41°Cbin recorded in October for an average of 0.07 hours per year but the result of 1978-1992 data gave the highest temperature in 39-40°C bin which occur in March for an average of 0.154 hours per year (Olorunmaiye and Ariyo 1998).

The modal dry bulb temperature for January, November and December occur in the 24-25°C dry bulb temperature bin which was equally reported earlier for 1978-1992 data by Olorunmaiye and Ariyo (1998). The modal dry bulb temperature for February, March, April and May occur at 25-26°C dry bulb temperature bin and 23-24°C dry bulb temperature bin is the modal bin for June, July, September and October. August has its modal temperature bin at 22-23°C. From Figure 1, the modal dry bulb temperature bin is 23-24°C. Tables 3 and 4 show the temperature distribution for each month of the year both when it is below or equal to 24°C and when it is above it.

This is a good indicator of energy that would be expended which largely depend on the ambient air temperature of the space that house the refrigeration system (Saidur et al (2005) and Olorunmaiye et al (2012)). From Table 3, the refrigerator is expected to consume lowest energy for July, August and September and from Table 4, the months of February, March, April and May would be months of highest energy consumption for refrigeration processes. The total number of hours that dry bulb temperature was above 24°C is 6284.84 hours and this is 71.70% of the total number of hours for the whole year. The month of March has 683.75 hours of dry bulb temperature above 24°C.

The significance of the results in Tables 4 and 5 has to do with the fact that 24°C and 50% relative humidity is the indoor design condition for comfort air conditioning systems. For the hours when the dry-bulb temperature is less than or equal to 24°C, the wall thermal transmission and the sensible part of ventilation/infiltration components of the cooling load will be zero. With the reduced cooling load, the on-off control of the air-handling unit (AHU) or the refrigerating unit of the air conditioning system will switch off the fan motor of the AHU or the compressor of the refrigerating unit most of the time and thereby save energy.

In the description of enhanced economizer function in air conditioner employing multiple water-cooled condensers (Patent Storm, 2010), it was reported that one of the two refrigerating circuits can be switched off while the cooling water from the cooling tower flows through the condenser of the second refrigerating unit and the heat exchanger economizer if the outdoor dry-bulb temperature is low enough and thereby save energy. When outdoor air temperature and/or relative humidity is very low such that the temperature of the cooling water from the cooling tower is appreciably lower than the temperature of the return air from the room, both refrigeration circuits can be switched off leaving the heat exchanger of the economizer alone to do the cooling of the conditioned space and thereby save more energy.

With the total number of hours that the dry-bulb temperature is less than or equal to 24°C falling from 2747.8 hours in the 1978 – 1992 data to 2481.2 hours in the 1995 – 2009 data as a result of global warming, it means the energy saving from using controls or economizer as described above will reduce.

From Figure 1 which compares results obtained from 1978-1992 data by Olorunmaiye and Ariyo (1998) with this present work based on 1995-2009 data, it is seen that only 6 bins; 16-17, 17-18, 18-19, 22-23, 23-24 and 24-25, have higher number of hours in 1978-1995 data than that of 1995-2009 data and these are at the lower end of the temperature range for Ilorin. Other bins which are in higher temperature range have higher number of hours in this recent work based on 1995 – 2009 data than those of earlier work based on 1978 – 1992 data. The results in Figure 1 and Tables 3 and 4 show clear indication of global warming in Ilorin. With this rise in temperature there would be higher energy consumed to cool for the period considered in this work than that of the earlier work by Olorunmaiye and Ariyo (1998).

The relative humidity bars for 1978 – 1992 data are taller or about equal to those of 1995 – 2009 data for most of the bins except the last two bins to the right in Figure 2. Since the dry-bulb temperature bars for 1995 – 2009 data are taller for most of the bins as shown in Figure 1, it means that the years 1995 – 2009 are drier i.e. having lower specific humidity or moisture content than 1978 – 1992. If this trend continues, it implies that evaporative cooling equipment like cooling towers will work better as a result of climate change.

The bin for relative humidity (RH) of 100 to 105% in Table 3 and Figure 2 represents the situation when the ambient air is foggy. Strictly speaking under that condition, the RH of the air is 100% but it is mixed with tiny droplets of water.

5. CONCLUSION AND RECOMMENDATIONS

The statistical analyses of the dry bulb temperature and relative humidity of Ilorin for 15-year period of 1995-2009 have been carried out. The month of March happened to be the hottest month. August is the month with the lowest monthly mean dry bulb temperature. The following are the bins where most temperature values for the months occur 22-23, 23-24, 24-25 and 25-26°C. The modal dry bulb temperature bin is 23-24°C which has the average of 512.31 hours per annum. This work presents evidence of global warming for Ilorin, as the bin data for 1995 – 2009 show that, that period is warmer than 1978 – 1992. The months of July, August and September will have reduced energy consumption by refrigerators while much energy would be expended in the months of February, March, April and May.

The study carried out in this work also showed that the 1995 – 2009 period is drier than the period 1978 – 1992. If this climate change trend continues, evaporative cooling devices will continue to work better in Ilorin. In the light of the results obtained in this work, it is recommended that regular review of these analyses for subsequent periods should be done to monitor the change in ambient temperature and relative humidity of cities in Nigeria and implication on energy consumption in refrigeration systems. For future work, detailed analysis of monthly rainfall data should be done to correlate it with relative humidity and dry-bulb temperature and to see further evidence of climate change.

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