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Statistical Analysis of Weather Data of Abuja and Minna with Respect to Air Conditioning Processes

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Abstract

One of the ways in which human beings adapt to climate change is through the application of refrigeration and air conditioning systems. The effectiveness of these systems depends on the weather of the environment in which they operate. The aim of this work was to carry out statistical analysis on fifteen-year (1995 – 2009) hourly dry-bulb temperature (T_{db}) and relative humidity (RH) data for Abuja and Minna, obtained from the Nigerian Meteorological Agency (NiMet). The objectives of the work for each location were: compilation of bin data for T_{db} and RH, and two-dimensional bin data of T_{db}/RH; computation of the number of hours in each month in which appreciable evaporative cooling can occur (hours in which $T_{db} \geq 32.2^oC$ along with RH ≤ 50%); and calculation of the number of hours that the T_{db} and the coincident RH fell in the comfort zone for each month. Microsoft Excel (2007 version) was used for the statistical analysis and bin widths of 1°C and 5% were chosen for T_{db} and RH, respectively. The RH modal bin for both locations occurred in the 90 – 95% bin for 1077.5 and 812.7 hours for Abuja and Minna, on the average per year, respectively. For T_{db}, the modal bins for Abuja and Minna were 23 – 24°C and 24 – 25°C for averages of 885.4 and 795.8 hours per year, respectively. There were six months (January through April, November and December) in which appreciable evaporative cooling occurred at the two locations for average totals of 1115 and 1340 hours per year, for Abuja and Minna, respectively. The average numbers of hour in which the weather was in the comfort zone were 1272 and 1364 hours per year and with appropriate use of humidifiers and dehumidifiers, additional 4642 and 4141 hours per year could be brought into the comfort zone at Abuja and Minna, respectively. Since the number of hours in which a dehumidifier is needed is much greater than the number of hours in which a humidifier is required at each location, dehumidifier is a more useful appliance than humidifier at both Abuja and Minna.

Keywords

Air conditioning processes, dry-bulb temperature, relative humidity, evaporative cooling, comfort zone, humidifier, dehumidifier.

1.0 Introduction

The air conditioning processes most appropriate to be used for a space depend on the prevailing weather conditions at that location. The following are different types of air-conditioning processes: humidification, dehumidification, cooling, heating and evaporative cooling. Humidification and dehumidification can be combined with either cooling or heating as reported by Bright Hub Engineering (2009).

Air conditioning systems are broadly classified as comfort air conditioning and industrial air conditioning. The purpose of comfort air conditioning is supplying air of the required dry bulb temperature and relative humidity for human comfort and health. This category of air conditioning systems is employed at home, offices, shops and event centres to mention a few (Khurmi and Gupta, 2010). On the other hand industrial air conditioning systems are employed for proper working of machines, for research purposes and in manufacturing processes. This is needed to keep an industrial outfit at a particular dry bulb temperature and relative humidity. Some industries such as paper mills, photo-processing plants and printing press among others require particular types of air conditioning processes to produce high quality products (Stoeker and Jones, 1982; Khurmi and Gupta, 2010; Awolola and Olorunmaiye, 2019).

Change in average ambient temperature is a good evidence of climate change and several methods may be employed to ameliorate the effect of the scourge of high ambient temperature. Responses to climate change can be divided into two categories, namely: mitigation and adaptation. A response under mitigation category either reduces the sources or enhances the sinks of greenhouse gases. Orlove (2005) observed that adhering to mitigation responses results in overall global benefits. Responses under the category of adaptation aim at adjusting to real or expected climate stimuli or their effects both on natural or human systems, and thereby reduce the destructive effects or exploit any beneficial opportunity (Orlove, 2005). One of the ways in which human beings adapt to climate change is through the application of refrigeration and air conditioning systems. In their comparison of adaptation to and mitigation of climate change, Zhao et al (2018) observed that both mitigation and adaptation share a common ultimate objective which is sustainability and development of human society with developed countries focusing more on mitigation actions while less developed countries which are highly vulnerable to climate change focus more on adaptation. Tol (2005) reported that adaptation may affect mitigation efforts, for example, employing air conditioning as an adaptation response to summer heat could increase emission of greenhouse gases. Tol (2005) also observed that: mitigation responses have global benefits whereas adaptation responses have regional benefits at best; and mitigation has long term effect since there is a long residence time for greenhouse gases in the atmosphere but the effect of an adaptation measure is immediate as it yields benefit of reduction of vulnerability to climate variability.

Several researches have been done on the major weather variables because of climate change. Adepitan et al (2019) reported their work of modeling diurnal variation of relative humidity, air temperature and solar radiation at Ota using minute interval data and hourly interval data gathered at the Covenant University Meteorological Centre for the four-month period September – December, 2012. However, there were missing data for November which made it to be excluded. The other months' complete data were then used for the curve fitting with four different functions employed out of which the best fit was found to be Fourier series and the models of the minute interval data curves were found to be more accurate than the models of hourly interval data. Yuan et al. (2018) investigated the effect of recent climate change on hourly weather data for design of heating, ventilation, and air conditioning (HVAC) systems for Osaka, Japan and they came up with a new design data based on more recently measured weather data of 2001-2015 for Osaka obtained from Japan Meteorological Agency, from which the effect of climate change on weather data was discovered.

Al-Salihi (2014) observed that a major challenge of the work on analysis of weather data is non-availability of weather data in electronic form which makes collection of the data and turning them to digital form to be time consuming, hence this non availability causes restriction of the quantity of data used in such work. Adeyemi et al. (2019), considering Ikeja, Lagos as a departure place for launching and operating spacecraft, carried out statistical analysis on fifteen-year (1995-2009) weather data of Ikeja to obtain 0.4, 1.0, 2.0, 97.5, 99.0 and 99.6 annual percentiles cumulative frequency of occurrence, medians of extreme lows and extreme highs for dry bulb temperature (T_{db}) and relative humidity (RH) to provide values of design parameters for HVAC systems of space crafts. To check for global warming, NiMet data for the year 1995 and weather forecast predicted by an earlier worker for year 2015 were used to compute the average monthly dry bulb temperature for each month of the year and it was also found that the average yearly dry bulb temperature for 2015 was only 0.15°C higher than that of 1995 (Adeyemi et al, 2019).

There are earlier works in which hourly weather data of dry bulb temperature and relative humidity for some locations were analyzed and related to refrigeration and air-conditioning systems. From the results of analysis of weather data of Yola and Maiduguri, Olorunmaiye and Awolola (2018) reported that the performance of evaporative coolers will be poor in the months of July, August and September and the cost of operating cooling systems will be minimal in October through February resulting from low relative humidity with coincident low dry bulb temperature.

From the statistical analysis of fifteen-year hourly dry bulb temperature and relative humidity data of Bauchi and Jos, the modal bins were: 23 – 24 °C and 18 – 19 °C; and 20 – 25 % and 95 – 100 %, for Bauchi and Jos, respectively, as was observed in a research by Olorunmaiye and Awolola (2017). For Enugu and Owerri, Awolola and Olorunmaiye (2018) carried out statistical analysis of dry bulb and relative humidity data and found that the hours in the comfort zone can be increased by employing dehumidifiers in homes for both cities; and preservation of agricultural produce can be equally improved.

Awolola and Olorunmaiye (2019), reported from the results of statistical analysis of fifteen-year weather data of Abuja that 1027.9 hours out of the 8766 hours in the year fall within relative humidity range 45-55% which is conducive for good quality printing. Therefore, application of dehumidifiers was recommended to bring down the relative humidity of additional hours to the relative humidity range of 45-55 % for high quality printing. In another work investigating the feasibility of utilizing evaporative coolers in seven locations in Nigeria which included Minna, Awolola and Olorunmaiye (2018) found out that evaporative coolers can be employed to a high degree in Minna.

It is expected that climate change would have affected the outdoor design conditions for air conditioning systems in Nigeria which were obtained by Shoboyejo and Shonubi (1974) from statistical analysis of 1951- 1965 weather data. On this premise, Olorunmaiye and Awolola (2017) from statistical analysis of hourly fifteen-year dry-bulb temperature for 18 locations in Nigeria (Abuja, Bauchi, Benin-City, Calabar, Enugu, Ibadan, Ikeja, Ilorin, Jos, Kaduna, Kano, Maiduguri, Minna, Ondo, Owerri, Port-Harcourt, Sokoto and Yola) computed the dry-bulb temperature corresponding to 0.4, 1.0 and 2.0 % annual cumulative frequency of occurrence and they also found the mean coincident

RH for each of these T_{db} values to serve as outside design conditions for air-conditioning systems for those locations.

The aim of this work is to carry out statistical analysis of fifteen-year hourly dry-bulb temperature and relative humidity data of Abuja and Minna with respect to air-conditioning processes. The objectives of the work are: computation of bin data from the hourly dry-bulb temperature and relative humidity data of Abuja and Minna; computation of the two-dimensional dry-bulb temperature/relative humidity bin data for each location; and using the results obtained to determine the number of hours in which the T_{db} and the coincident RH combination is within the comfort zone and also the number of hours in which appreciable evaporative cooling can be experienced in both locations.

2.0 Methodology

2.1 Need for the Study

There is need for this type of work because locations in Nigeria are often left out when statistical analysis is carried out to generate a database of climatic design information from the weather data obtained from many places in the world. For example, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provided climatic design information for 8,118 locations in the United States of America, Canada and other countries but Nigerian cities were not included (ASHRAE, 2017). In the 2005 and 2009 editions of ASHRAE Handbook-Fundamentals which provided climatic design information for 4,422 and 5,564 locations in the world, respectively, locations in Nigeria were also missing. The omission of locations in Nigeria from the database of climatic design information in the 2013 edition of ASHRAE Handbook- Fundamentals was also pointed out by Adeyemi et al (2019). One major hindrance to including locations in Nigeria is the problem of the weather data from Nigerian Meteorological Agency (NiMet) not being available in digital form. There is also the problem of inadequate weather data acquisition by NiMet such as wet bulb temperature data being available on three-hourly basis instead of on an hourly basis. However, Roth (2021) revealed that Lagos, Nigeria is one of the 9,237 stations that climatic design information will be provided for in the 2021 edition of ASHRAE Handbook-Fundamentals to be published later in 2021. It is not certain if any other location in Nigeria will be included in the 2021 edition.

While some pieces of information provided by ASHRAE as climatic design information can be obtained from T_{db} bin data and RH bin data, which are to be compiled for Abuja and Minna in this work, the limited pieces of information on two-dimensional bin data presented by ASHRAE are coincident average wet bulb temperature to 0.4, 1.0 and 2% annual percentile T_{db}, etc. In this work, detailed two-dimensional T_{db}/RH bin data are to be presented which will be useful in guiding engineers in the selection, sizing and operation of domestic and industrial appliances such as humidifiers and dehumidifiers.

2.2 *Study Area*

The two locations considered in this work are: Abuja in the Federal Capital Territory (FCT) located on latitude 9°03′26″N, and longitude 7°29′33″E at an altitude of 244 m above sea level; and Minna in North Central Zone of Nigeria on latitude 9°36′50″N, and longitude 6°33′24″E at an altitude of 262 m above sea level.

2.3 *Data Collection*

Meteorological data of dry-bulb temperature and relative humidity recorded hourly were obtained from the Nigerian Meteorological Agency (NiMet), Oshodi, Lagos. The data were for the fifteen-year period 1995 – 2009 for Abuja and Minna which were made available on NiMet form 131/3. As at the time in year 2011 when the research work reported here started, the sets of data for the years 1995- 2009 were the most current fifteen-year data that could be obtained from NiMet. There is often a long delay before the data gathered for a year is compiled and made available to researchers.

2.4 *Data Analysis Procedures*

The data were stored and analyzed with Microsoft Office Excel 2007 version. Each location's data were kept in an excel file of twenty-four sheets for twelve months for both dry-bulb temperature and relative humidity. Each sheet contained the 15-year data for a particular month. This was done so that the visual basic codes written can pick data from two sheets of the same month for dry-bulb temperature and relative humidity to compile bin data for each of dry-bulb temperature (T_{db}) and relative humidity (RH) and also the two-dimensional bin data of T_{db}/RH.

The Visual Basic codes which were written for the compilation of the bin data of T_{db} and RH and the two-dimensional bin data of T_{db}/RH can be found elsewhere (Awolola, 2018). The two dimensional bin data indicates the coincidence of T_{db} with RH. One degree Celsius was the size of the dry-bulb temperature bin while five percent was used for the relative humidity bin size. The results for the 12 months of the year were summed up to obtain yearly data so as to have a yearly report. The number in each cell for the two–dimensional bin data gives the average number of hours per year that the dry-bulb temperature and relative humidity coincide during the fifteen-year period.

3.0 Results and Discussion

3.1 Dry-bulb Temperature and Relative Humidity Bin Data

For both Abuja and Minna, Figures 1 and 2 are the computed dry-bulb temperature bin data and relative humidity bin data, respectively. The hours shown in the bar charts are the average numbers of hours in a year that the T_{db} or RH falls within that bin, for each location.

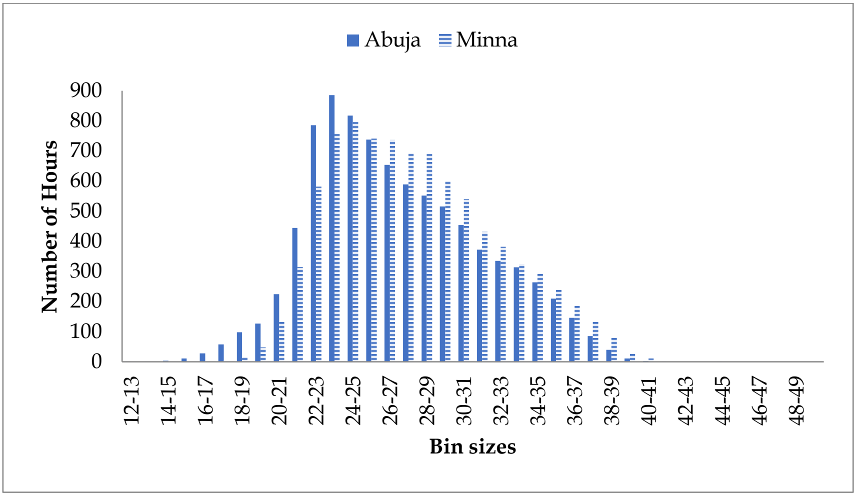

Figure 1. The dry-bulb temperture bin data for Abuja and Minna

From Figure 1, the minimum temperature is in the 12-13°C bin and it occurs for both Abuja and Minna for an average of 0.067 hour per year; this is insignificant. The maximum temperature occurs in the 48-49°C bin at Minna while Abuja has the maximum temperature in the 44-45°C bin, each occurring for an average of 0.067 hours in a year. The value 0.067 hours computed for the minimum and maximum temperature bins shows that each of these extreme temperatures were observed for only one hour during the fifteen-year period for which the weather data were analyzed (1/15 = 0.067). The modal bins for Abuja and Minna were 23-24°C and 24-25°C for averages of 885.4 and 795.8 hours per year, respectively.

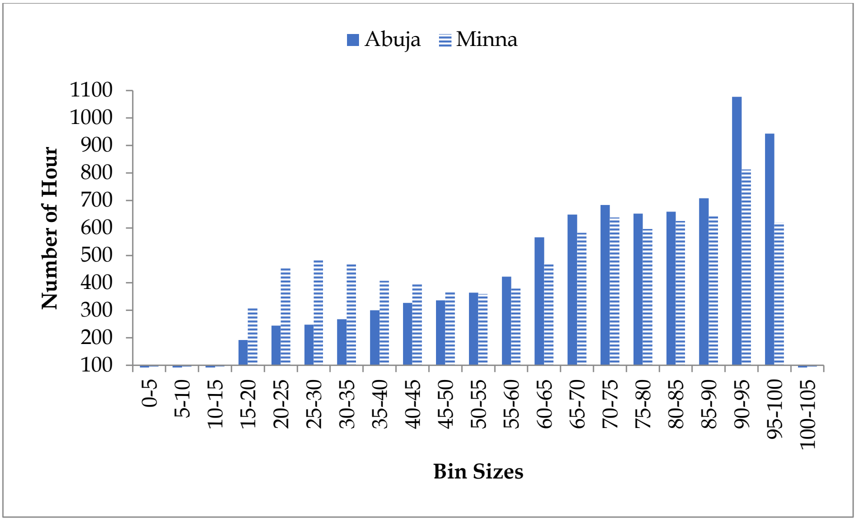

Figure 2. The relative humidity bin data for Abuja and Minna

From the relative humidity bin data shown in Figure 2, the minimum hourly relative humidity occurs in the 5-10% bin for both locations. The maximum hourly average relative humidity is in 100-105% bin. This bin represents foggy weather. These occur for relatively insignificant number of hours in a year. The modal bin for the two locations occurred in the 90-95% bin for about 1077.5 hours for Abuja and 812.7 hours for Minna, on the average per year.

3.2 *Two-dimensional Bin Data for Dry-bulb Temperature/Relative Humidity*

The compiled yearly two-dimensional bin data for both locations are presented in Tables 1 and 2 for Abuja and Minna, respectively.

Two-dimensional bin data such as shown in Tables 1 and 2 were computed for each of the 12 months in the year. The results in Tables 1 and 2 were obtained from adding the hours in the corresponding cells for the twelve months. The results shown in Figures 3 – 6 were obtained from the monthly two-dimensional bin data used to compile Tables 1 and 2.

Table 1: The Yearly Two-Dimensional Bin Data of Dry-Bulb Temperature and Relative Humidity for Abuja

RH	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105
Temp																					
12-13	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0
14-15	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.4	1.0	0.8	0.1	0.3	0.1	0.0	0.0	0.0
15-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	1.7	1.5	2.6	1.6	1.7	0.4	0.4	0.1	0.0	0.0
16-17	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	1.2	2.3	3.4	4.5	3.9	4.1	4.2	2.0	1.4	0.8	0.0	0.0
17-18	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	1.5	2.4	5.6	6.3	7.3	8.4	7.5	7.3	5.3	3.8	1.1	0.1	0.0
18-19	0.0	0.0	0.0	0.0	0.1	0.4	0.8	2.1	3.6	7.3	8.1	9.9	11.8	10.5	12.9	12.1	8.0	6.5	3.9	0.2	0.0
19-20	0.0	0.0	0.0	0.0	0.3	0.5	1.8	3.0	4.8	9.9	10.4	13.5	12.1	10.2	15.1	13.7	8.8	12.3	7.0	2.1	1.3
20-21	0.0	0.0	0.0	0.1	0.4	1.7	3.2	5.6	9.7	9.6	11.0	11.5	13.2	16.2	13.8	16.9	15.5	15.8	19.1	46.0	14.9
21-22	0.0	0.1	0.0	0.3	0.6	2.7	5.0	10.0	10.3	11.8	11.5	11.1	17.0	15.9	18.3	18.7	18.1	21.2	67.6	182.5	22.1
22-23	0.0	0.0	0.0	0.6	1.7	3.9	8.4	11.4	14.2	12.1	13.0	14.8	16.0	13.6	19.6	22.8	26.6	49.4	196.9	343.9	16.4
23-24	0.0	0.0	0.0	0.7	2.1	4.4	8.6	9.8	13.0	14.6	11.6	16.2	13.5	17.2	18.3	26.7	40.2	97.1	333.4	253.8	4.3
24-25	0.0	0.0	0.1	0.9	4.4	7.2	10.9	12.8	12.8	11.2	13.3	12.8	17.1	16.9	22.4	40.0	80.8	186.9	289.2	76.7	1.5
25-26	0.0	0.0	0.2	1.4	5.8	9.6	12.5	14.6	13.4	12.9	13.5	16.2	19.3	25.0	37.2	73.0	158.4	192.3	113.1	19.0	0.5
26-27	0.0	0.0	0.3	2.0	5.5	11.0	11.7	12.1	13.2	13.6	13.3	16.0	22.0	33.7	63.9	135.3	178.5	87.2	27.0	7.3	0.5
27-28	0.0	0.0	0.1	2.4	6.4	10.4	11.1	12.3	12.6	11.2	12.7	17.0	33.7	53.4	131.6	160.3	81.9	18.6	8.5	4.2	0.1
28-29	0.0	0.0	0.0	2.8	8.9	10.2	12.1	12.0	12.6	13.9	17.4	24.0	43.9	100.9	174.1	84.3	19.9	8.0	3.9	2.8	0.0
29-30	0.0	0.0	0.6	5.2	11.3	11.8	11.4	13.3	12.9	13.2	20.7	38.5	78.4	155.9	102.9	24.3	7.5	3.0	2.7	1.9	0.2
30-31	0.0	0.0	0.7	7.4	14.3	15.2	13.9	15.6	14.2	19.6	32.3	46.9	115.2	116.8	27.1	6.3	3.8	1.4	1.7	1.4	0.2
31-32	0.0	0.1	1.8	11.8	18.3	18.0	16.2	15.1	17.8	26.3	39.0	62.7	95.3	36.1	7.9	2.1	1.5	1.1	0.6	0.7	0.1
32-33	0.0	0.0	2.6	17.5	26.0	22.8	23.6	21.6	23.6	35.5	52.3	62.5	35.5	6.2	2.4	1.1	0.7	0.4	0.1	0.4	0.1
33-34	0.0	0.2	7.5	28.0	33.1	28.6	27.1	26.9	36.4	42.3	44.3	29.2	5.7	2.2	0.8	0.3	0.3	0.2	0.4	0.3	0.0
34-35	0.0	0.2	8.0	29.4	32.7	28.7	27.0	26.2	37.5	39.6	24.7	6.2	1.3	0.8	0.5	0.2	0.3	0.2	0.3	0.0	0.0
35-36	0.0	0.2	11.7	29.2	30.2	25.4	21.5	26.9	35.5	21.1	5.3	0.8	0.5	0.3	0.5	0.5	0.1	0.1	0.1	0.0	0.0
36-37	0.0	0.3	10.7	25.7	19.3	15.4	19.1	29.0	19.3	5.1	1.2	0.5	0.0	0.3	0.1	0.1	0.1	0.1	0.0	0.0	0.0
37-38	0.0	0.2	8.0	15.1	12.9	11.5	14.1	14.9	6.3	0.9	0.5	0.3	0.5	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
38-39	0.0	0.4	7.4	7.0	6.9	6.8	5.5	3.6	1.0	0.3	0.3	0.3	0.2	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0
39-40	0.0	0.1	1.8	3.4	2.0	1.2	1.9	0.4	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
40-41	0.0	0.1	0.3	0.8	0.8	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41-42	0.0	0.0	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43-44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44-45	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The average number of hours the weather is in the comfort zone for the 12 months of the year are shown in Figure 3 and the number of hours to the left of the comfort zone in which humidifiers can be used to bring temperature and humidity in the occupied space into the comfort zone are shown in Figure 4. The number of hours to the right of the comfort zone in which dehumidifier can be applied to bring T_{db}/RH into the comfort zone are shown in Figure 5. The number of hours in which high level evaporative cooling can be employed is depicted in Figure 6.

The comfort zone shown as broken line rectangles in Tables 1 and 2, are enclosed within the dry bulb temperature of 18°C to 29°C and relative humidity of 30% to 70%. When the T_{db}/RH combination lies in this zone, human beings are comfortable even without cooling the air in the spaces occupied. Good ventilation and application of fans is all that they need. The total numbers of hours that the weather falls in this zone are on the average 1272 hours and 1364 hours per year for Abuja and Minna, respectively.

Table 2: The Yearly Two-Dimensional Bin Data of Dry-Bulb Temperature and Relative Humidity for Minna

RH	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105
Temp																					
12-13	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13-14	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15-16	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.0
17-18	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.4	0.5	0.2	0.1	0.5	0.4	0.3	0.6	0.3	0.3	0.3	0.1	0.0	0.0
18-19	0.0	0.0	0.0	0.1	0.7	1.3	1.4	1.1	1.4	1.1	1.5	1.1	1.1	1.6	1.2	1.3	1.3	0.3	0.3	0.6	0.0
19-20	0.0	0.0	0.1	0.4	2.5	3.3	3.4	3.5	4.1	2.3	4.4	3.9	3.9	2.9	3.3	2.1	2.9	1.3	0.5	2.6	0.9
20-21	0.0	0.0	0.1	1.1	4.5	5.3	6.8	9.0	10.4	9.1	10.3	6.6	6.9	6.0	5.9	5.6	4.9	6.5	6.8	21.8	5.2
21-22	0.0	0.0	0.5	2.6	5.6	12.3	15.7	14.9	16.8	15.8	12.6	11.0	8.0	7.5	7.3	8.3	9.4	12.0	46.6	93.0	15.0
22-23	0.0	0.0	0.3	3.1	9.2	16.5	21.9	21.5	19.5	18.1	16.1	12.3	9.5	9.0	8.9	9.7	15.5	37.7	137.6	202.8	12.0
23-24	0.0	0.1	0.8	3.9	13.4	20.5	25.1	23.2	22.9	19.0	15.0	10.3	8.5	10.5	11.2	14.1	26.4	86.0	249.0	192.2	5.2
24-25	0.0	0.1	1.0	5.6	18.6	23.3	27.5	22.3	21.5	17.6	16.8	10.2	11.7	12.4	15.7	23.8	69.7	179.9	243.7	72.6	1.9
25-26	0.0	0.2	1.9	8.3	22.2	26.6	26.2	20.8	20.4	16.5	16.0	12.3	11.5	15.5	26.3	59.4	151.9	195.4	91.9	17.6	0.6
26-27	0.0	0.0	1.8	9.2	25.8	29.9	29.3	24.0	19.8	19.5	15.5	14.9	19.3	24.1	54.4	128.0	201.4	88.5	23.4	7.4	0.3
27-28	0.0	0.1	2.7	11.6	25.2	26.6	25.4	20.9	19.0	17.7	14.3	17.0	27.2	48.9	120.5	179.2	102.1	22.4	6.3	3.4	0.2
28-29	0.0	0.1	2.7	15.0	24.9	27.1	26.9	22.4	19.4	19.7	18.1	21.6	42.5	89.1	197.2	120.2	28.8	7.6	3.3	3.3	0.1
29-30	0.0	0.2	3.5	17.7	27.3	26.8	26.2	22.9	17.3	17.7	17.0	31.6	66.5	147.1	134.5	33.9	6.1	2.6	1.6	0.8	0.0
30-31	0.0	0.3	6.2	22.2	27.7	30.3	26.5	20.2	19.5	20.2	24.9	45.4	99.2	143.4	41.8	6.8	2.6	1.1	0.8	0.6	0.0
31-32	0.0	0.2	6.2	23.5	30.6	28.8	25.4	20.0	21.1	21.4	35.5	62.5	95.1	51.9	6.1	1.7	1.0	0.3	0.2	0.3	0.0
32-33	0.0	0.8	8.2	26.4	34.7	36.1	28.9	21.2	22.9	30.0	47.6	66.9	45.0	9.0	1.5	1.0	0.3	0.5	0.3	0.7	0.3
33-34	0.0	1.6	7.7	29.2	38.6	38.4	29.1	23.2	30.2	34.5	46.3	32.5	10.4	1.2	0.5	0.4	0.1	0.3	0.1	0.0	0.0
34-35	0.0	1.3	9.3	34.7	37.8	40.7	29.8	26.6	30.3	35.0	30.3	12.7	1.9	1.0	0.2	0.3	0.1	0.1	0.1	0.1	0.0
35-36	0.0	1.0	9.9	32.3	39.3	32.0	24.5	23.4	30.1	31.5	11.2	3.5	1.0	0.3	0.1	0.2	0.1	0.0	0.0	0.0	0.0
36-37	0.0	0.8	10.4	24.3	31.2	21.1	21.8	27.4	27.9	13.3	3.8	1.5	0.6	0.6	0.1	0.1	0.2	0.0	0.0	0.0	0.0
37-38	0.0	1.5	9.6	20.5	17.4	16.6	22.6	24.1	14.6	4.1	1.4	0.4	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0
38-39	0.0	0.8	6.1	12.1	11.2	13.6	15.4	11.5	5.2	1.4	0.4	0.2	0.1	0.4	0.3	0.2	0.0	0.0	0.0	0.0	0.0
39-40	0.0	0.5	3.3	5.6	5.3	4.7	5.2	2.3	1.3	0.8	0.1	0.3	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
40-41	0.0	0.4	2.2	2.1	2.5	1.5	1.1	0.5	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41-42	0.0	0.6	0.4	0.6	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42-43	0.0	0.3	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43-44	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44-45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45-46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47-48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48-49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49-50	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The period in which appreciable evaporative cooling can occur is when dry-bulb temperature is greater than or equal to 32.2°C and relative humidity is less than or equal to 50%. Appreciable evaporative cooling zone is shown in each of Tables 1 and 2 as a rectangle at the bottom left corner. Evaporative cooling commonly used in arid zones, involves reducing the dry-bulb temperature while increasing the relative humidity in such a way that most of the latent heat of evaporation is obtained largely from the air. The dry-bulb temperature and the coincident relative humidity lie in the appreciable evaporative cooling zone for averages of 1115 and 1340 hours per year for Abuja and Minna, respectively.

The monthly hours in the comfort zone which are presented in Figure 3 can be improved upon in these locations either by humidification which is addition of moisture during periods of very low relative humidity (less than 50%) or dehumidification which involves removal of moisture from the air. The average numbers of hours per month in which humidifiers can be used in order to increase hours in the comfort zone are shown in Figure 4. The hours add up to 110 and 418 per year for Abuja and Minna, respectively. The average hours in which dehumidifiers can be used to bring the weather into the comfort zone are shown in Figure 5. The hours add up to 4532 and 3723 hours per year for Abuja and Minna, respectively. Thus by using dehumidifiers largely during the months of April to November and humidifiers from December to February, the total additional numbers of hour that can be brought into the comfort zone are 4642 and 4141 hours for Abuja and Minna, respectively. From these results, it can be seen that dehumidifiers will be far more useful than humidifiers in Abuja and Minna.

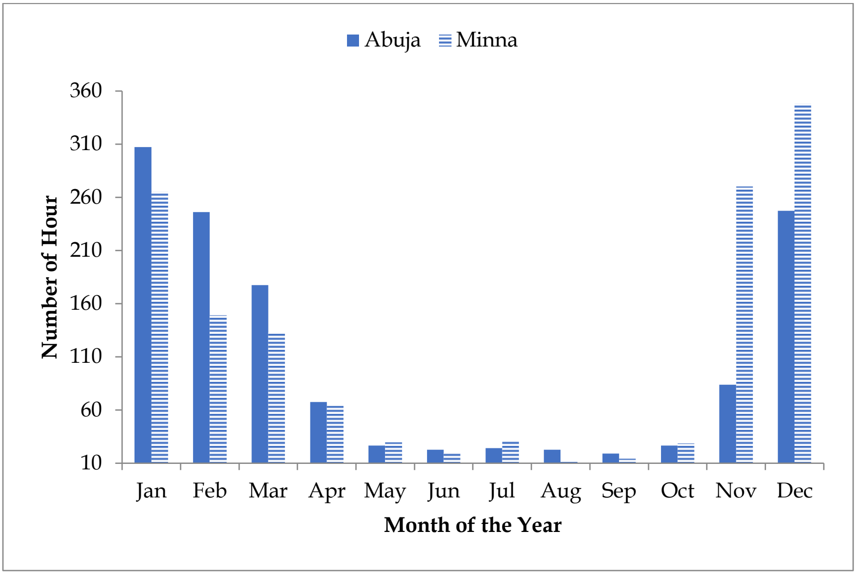

Figure 3. The average number of hours in which the weather is within the comfort zone for the twelve months of the year for Abuja and Minna

From Figure 3, the months of January through April, November and December had sizeable number of hours in the comfort zone for the two locations. The months of May through October had very small number of hours in the comfort zone because this is the period of rainy season with attendant high relative humidity. However, Abuja had higher number of hours in the comfort zone for January through April while Minna had higher number of hours in both November and December.

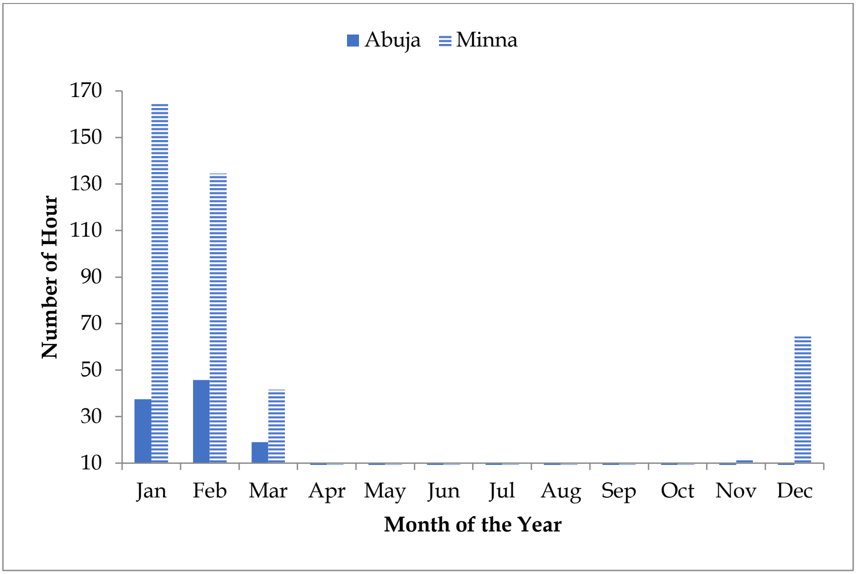

Figure 4. Number of hours in which the weather is above the comfort zone and humidifier can be used to attain comfort

From Figure 4, the hours in the comfort zone in Minna can be increased by using humidifier during the months of January, February, March and December. The hours in the comfort zone for Abuja can also be increased during the first three months of the year if humidifier is employed.

From Figure 5, the hours in the comfort zone can be increased by employing dehumidifiers in April through November for both locations. The hours for Abuja are higher than those for Minna for all the months with August having the highest values approximately equal to 677 hours for each of the two locations. This is because Abuja is more humid than Minna as can be seen in Figure 2.

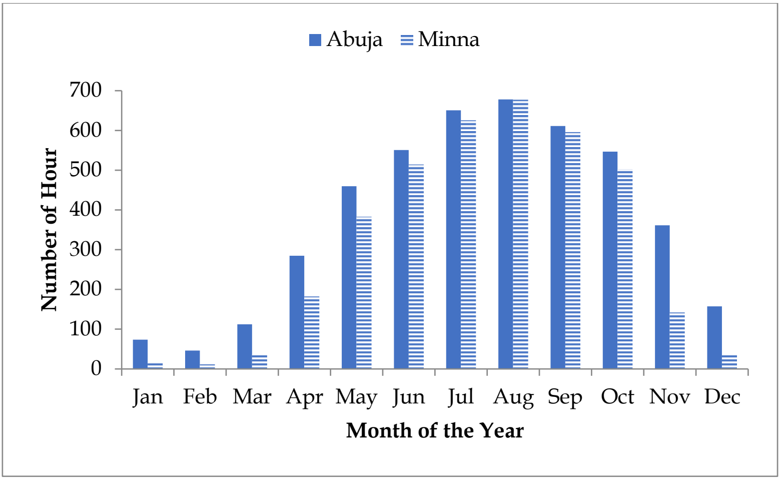

Figure 5. Number of hours in which the weather is below the comfort zone and dehumidifier can be used to attain comfort

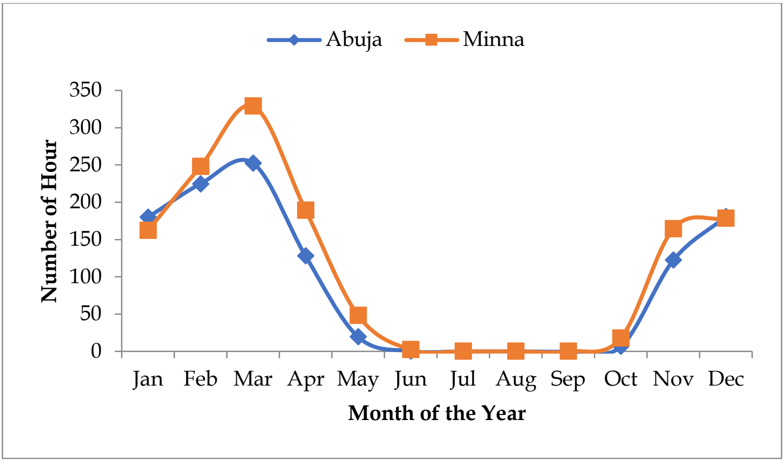

Figure 6. Number of hours in which the weather is within the appreciable evaporative cooling zone for the twelve months of the year

The numbers of hour for each month of the year at both locations during which high level of evaporative cooling can occur (T_{db} ≥ 32.2°C along with RH ≤ 50%) are presented in Figure 6. The month having the highest number of hours in the appreciable evaporative cooling zone is March for both Abuja and Mnna. Minna has an average of 1340.3 hours per year in the appreciable evaporative zone while Abuja has a total average of 1114.9 hours per year. The months of June through October have zero hours of appreciable evaporative cooling for both locations. This does not mean that evaporative cooling cannot occur during those months but rather that it will be weak if it occurs. It is only for hours in which RH is around 100 % that evaporative cooling is zero.

The results obtained in this work are useful for guiding engineers in selection of the appropriate type, sizing, and operation of household and industrial appliances such as humidifiers, dehumidifiers, ventilators and evaporative coolers.

3.3 Use of 1995-2009 Data

Hourly T_{db} and RH data for Abuja and Minna for the fifteen-year period 1995-2009 obtained from NiMet, were used in this work. Adeyemi et al (2019) also used 1995-2009 NiMet hourly T_{db} and RH data for Ikeja in their work. The results presented in this work remain valid and applicable until results obtained from the analysis of more recent meteorological data become available. The results from 1995-2009 data can then serve as a basis for comparison of results obtained in the future from more current data. The effect of climate change can then be seen from such comparison of results.

4.0 Conclusion

The statistical analysis of the hourly dry-bulb temperature and relative humidity data of Abuja and Minna have been carried out to generate bin data for each of the two weather variables and also two-dimensional bin data of dry-bulb temperature/relative humidity.

The following were arrived at:

(i) Abuja has 1272 hours out of the 8766 hours in a year, in the comfort zone while Minna has 1364 hours. With appropriate application of humidifiers and dehumidifiers, additional 4642 and 4141 hours can be brought into the comfort zone for Abuja and Minna, respectively.

(ii) There are six months in the year which are January through April, November and December in which appreciable evaporative cooling can occur for 1115 and 1340 hours per year at Abuja and Minna, respectively.

(iii) Dehumidifier is a far more useful appliance than humidifier for both Abuja and Minna

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