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THE COOLING SYSTEMS AND WEATHER STATISTICS OF MAIDUGURI AND YOLA - NIGERIA

J. A. Olorunmaiye[1*] and O. O. Awolola[2]

[1]*Department of Mechanical Engineering, University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria*

[2]*Department of Mechanical Engineering, The Federal Polytechnic, Ilaro, P.M.B. 50, Ilaro, Ogun State, Nigeria*

*Corresponding author's email address: adeolorunmaiye@gmail.com, lekanoba@yahoo.com

Tel.: +234-8036000053, +234-8027955316

Abstract

Bin data for dry bulb temperature, relative humidity and two-dimensional bin for dry bulb temperature - relative humidity were compiled using a fifteen-year hourly dry bulb temperature and relative humidity data for Maiduguri and Yola. The data were collected from Nigerian Meteorological Agency (NiMet), Oshodi, Lagos. The bins sizes of 1°Cand 5% were used for dry bulb temperature and relative humidity respectively. The number of hours in each month in which dry bulb temperature ≥ 32.2°C and relative humidity ≤ 50% during which appreciable evaporative cooling can occur and when dry bulb temperature/relative humidity pair was in the comfort zone were determined. The modal bin for dry bulb temperature (T_{DB}) and relative humidity (RH) are 25 - 26°Cand 15-20% for Maiduguri and 25-26°Cand 90-95% for Yola. April and March are the months that appreciable evaporative cooling usually occurs in the chosen locations and evaporative coolers could be applied during the months of March up to May. But from July to September the evaporative coolers perform poorly in both locations. During the months of October to February, low monthly costs of running the refrigerators and air conditioners significantly different from other months of the year, were indicated by the results.

Key words: Bin data, dry bulb temperature, relative humidity, evaporative cooling, comfort zone, refrigerators and air conditioners

1. Introduction

The world is experiencing increase in ambient temperature which resulted from several human activities that releases greenhouse gases in to the atmosphere. This experience termed global warming has caused increase in energy and water consumption and equally badly affects human wellbeing (Karl and Easterling, 1999).

Human comfort in the work place is a challenge in temperate zone especially in summer, hence there is need to cool occupied spaces. On the other hand in tropical countries like Nigeria, cooling is necessary almost all year round, especially in hot and humid weather conditions.

Besides human discomfort and loss of concentration at work, extreme heat affects health and productivity. It is difficult to dissipate heat when dry bulb temperature is extremely high especially if the relative humidity is also high (Harris, 1983). Ambient temperature is a factor to be considered when performance of certain types of equipment used in cooling systems is an issue. There is a reduction of heat rejection of an air cooled condenser of vapour compression refrigeration system when the dry bulb temperature of the environment increases (Olorunmaiye and Ariyo, 1998).

1.1 Review of Previous Investigation on Global Warming

A number of studies have been carried out on the effect of global warming on energy utilized by cooling systems. Olorunmaiye *et al.* (2012) investigated the effect of change in ambient temperature on energy consumption of refrigerators by operating the refrigerator at three ambient temperature conditions and they found that energy consumption by refrigerator increases with increase in ambient temperature of the space where the refrigerator is operated. Saidur *et al.* (2005) found that among the three independent variables affecting power required for operating the refrigerator-freezer (ambient temperature, load in the refrigerator-freezer and the number of times the door was opened per hour), ambient temperature had the greatest effect. A report by the energy commission of California said that with increase in ambient temperature, higher energy utilization was anticipated. (Xu *et al.,* 2009).

Other studies have been done on weather statistics of some locations in Nigeria by earlier researchers which included Maiduguri and Yola. Shoboyejo and Shonubi (1974) used 1951-1965 meteorological data to compute the outside design condition of air conditioning systems for some locations in Nigeria among which were Maiduguri and Yola in which they obtained the outside design condition of dry bulb and wet bulb temperatures for 1%, 2½%, and 5% confidence values for the four warmest months assuming Gaussian Probability distributions.

Olorunmaiye and Awolola (2015) used 1995-2009 meteorological data of 18 locations which included Maiduguri and Yola to compute 1%, 2½%, and 5% confidence values for dry and wet bulb temperatures. The values they obtained for both dry-bulb and wet-bulb temperatures were higher than corresponding values obtained by Shoboyejo and Shonubi (1974) for both Maiduguri and Yola.

Statistical analysis of 1995-2009 dry bulb temperature and relative humidity data for Ilorin, was done and it was reported (Olorunmaiye and Awolola, 2015) that there is increase in the values got when compared with those obtained by Olorunmaiye and Ariyo (1998) which were based on 1978-1992 dry bulb temperature and relative humidity data for Ilorin. The above results show that Nigeria is not excluded from the scourge of global warming and climate change.

Wet bulb temperature is an important parameter which affects the performance of evaporative cooling systems such as earthen pots, evaporative coolers used as refrigerators (Olorunmaiye, 1995) and evaporative coolers used in dry arid areas for air conditioning (Harris, 1983). High degree of evaporative cooling can be experienced when the system is in an environment in which high dry bulb temperature (≥32.2°C) and low relative humidity (≤50%) occur concurrently.

The concept of effective temperature has been developed from the research of the American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE) relating temperature, humidity and air movement to human comfort. Effective temperature lines on wet bulb temperature versus dry bulb axes are lines joining different combination of dry bulb temperature and relative humidity which give the same feeling of comfort to a high percentage of people equally clothed and equally active, for a given air velocity (0.0762-0.1270 m/s for the comfort chart for still air) (Harris, 1983). The comfort zone in the chart is between effective temperatures of 17.2°C and 23.9°C. The dry bulb temperature and the relative humidity of the four corners of the comfort zone are: 18.3°C/70%, 25.7°C/70%, 19.8°C/30%, and 29.1°C/30%.

Maiduguri is located on latitude 11.85°N and longitude 13.08°E with an altitude of 345m above sea level, Maiduguri falls within the semi-arid zone of West Africa geographically and it experiences little rainfall and more of dry season (Abdulrahim *et al,* 2012). Yola is the capital of Adamawa State, Nigeria. The town is situated at an altitude of 186m. The geographical coordinates are 09°14'N and 12°28'E. Yola is located on the Benue River and it has a mean temperature of 28.3°C (Alexander, 2015)

The aim of the work reported in this paper is to carry out statistical analysis on 15-year data of hourly dry bub temperature and relative humidity of both Maiduguri and Yola in the North East Geo-political zone of Nigeria, by compiling the bin data for dry bulb temperature, relative humidity and two - dimensional dry bulb temperature/ relative humidity. The proportion of the hours in the year when the weather is within the comfort zone and the amount of time a high level of evaporative cooling could be experienced will equally be estimated.

2. Materials and Methods

Fifteen year hourly dry bulb temperature and relative humidity data for Maiduguri (1995-2009) and for Yola (1994-2008) were obtained from Nigerian Meteorological Services (NiMet), Oshodi, Lagos. The data were keyed into the computer using Microsoft Office Excel 1997-2003 version. From the meteorological data, the bin data for both dry bulb temperature and relative humidity were compiled. Microsoft Excel codes were written to do the compilation of both dry bulb temperature and relative humidity bins for both locations while Visual Basic codes were written to compile two- dimensional dry bulb temperature/relative humidity bin for the two locations. The bins width of 1 degree Celsius for dry bulb temperature and 5 percent for relative humidity were employed.

3. Results and Discussion

(i) Diurnal variation of the monthly average weather conditions

Figures 1 and 3 show the diurnal variation of the monthly average hourly dry bulb temperature for January to December for Maiduguri and Yola respectively. The diurnal variation of the monthly average hourly relative humidity for January to December for Maiduguri and Yola are shown in Figures 2 and 4. The hours of the day in the abscissae of the sets of graphs are Greenwich Mean Time (GMT) since GMT was used as the time base for the data collected from Nigerian Meteorological Agency (NiMet). Figures 1 through 4 show that, for any month, as the average values of hourly dry bulb temperature increases there is corresponding decrease in the average values of hourly relative humidity. Thus there is negative cross correlation coefficients of dry bulb temperature and relative humidity for all the months. The variations of relative humidity shown in Figures 2 and 4 are caused majorly by diurnal changes in dry bulb temperature. As air warms up, the moisture it can carry per unit mass increases and its relative humidity is lowest in the afternoon around 15.00 Greenwich Mean Time (GMT) at the highest dry bulb temperature and conversely relative humidity is highest at 6.00 GMT at the lowest dry bulb temperature, this was equally reported by Olorunmaiye and Ariyo (1998) in respect of Ilorin weather conditions based on 1978-1992 data.

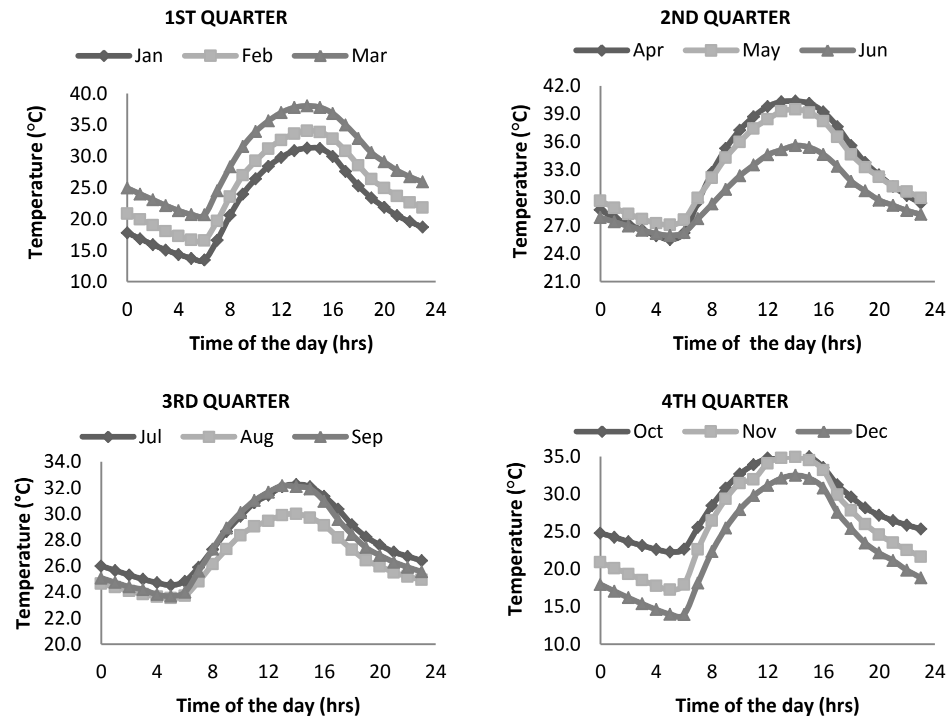

Figure 1: Diurnal variation of monthly-average hourly dry bulb temperature forMaiduguri

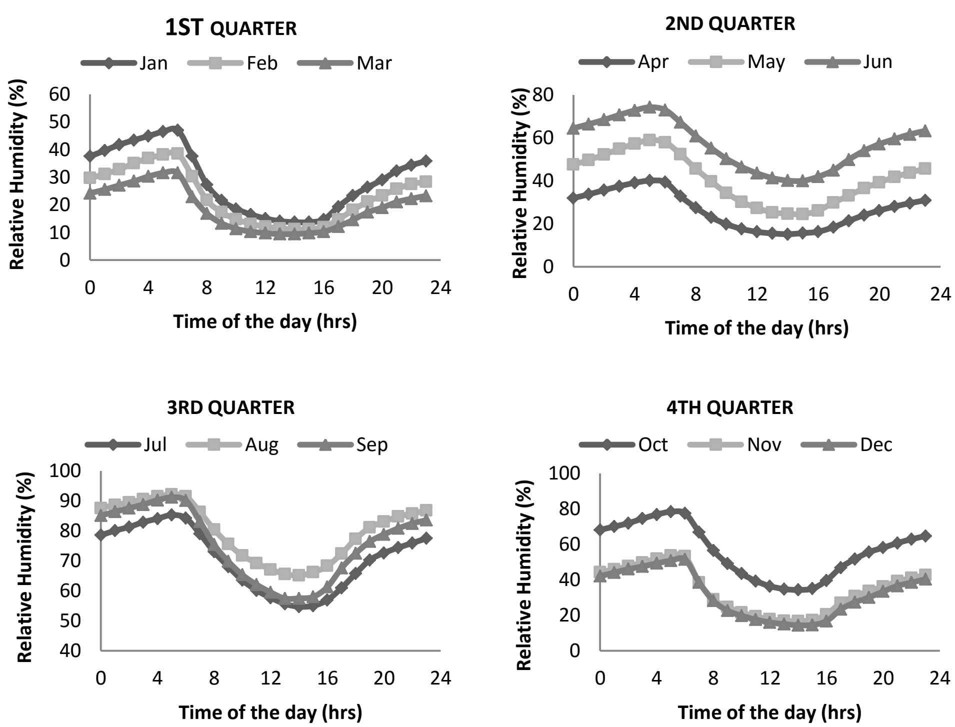

Figure 2: Diurnal variation of monthly-average hourly relative humidity for Maiduguri

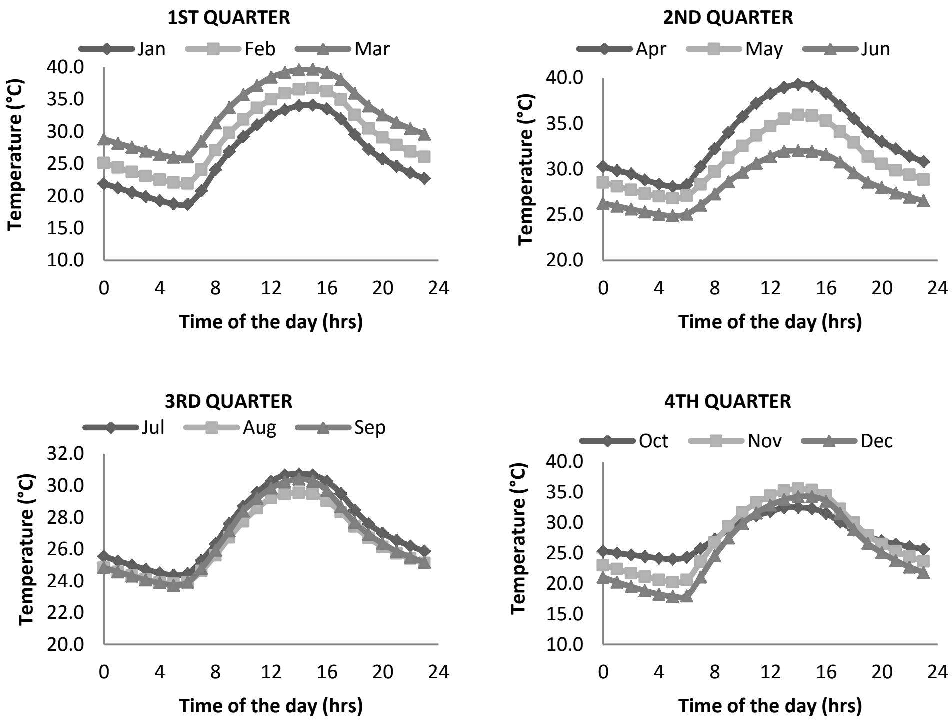

Figure 3: Diurnal variation of monthly-average hourly dry bulb temperature for Yola

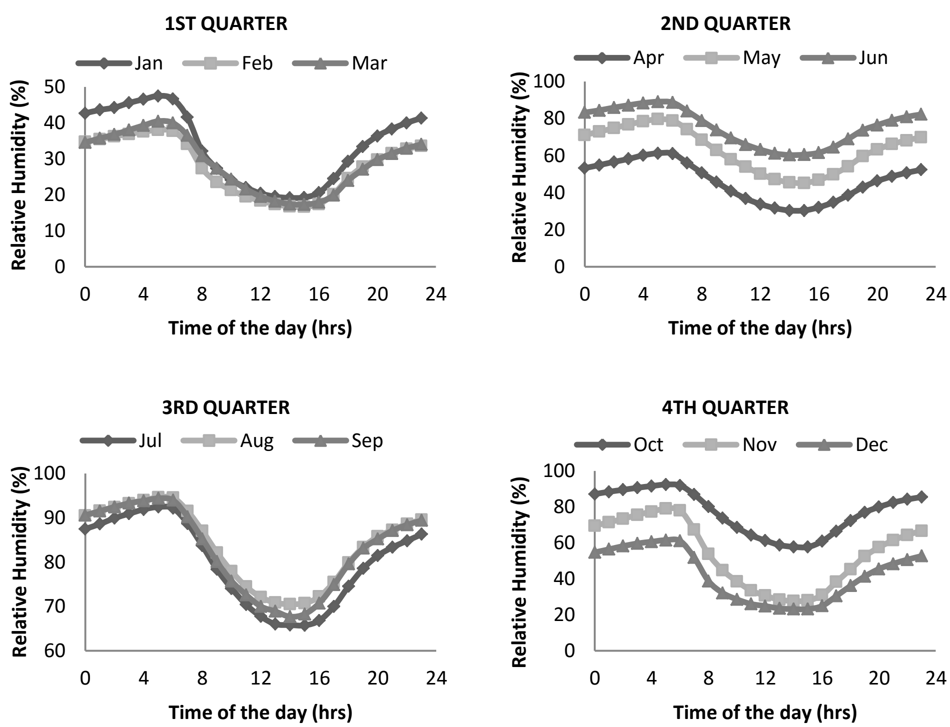

Figure 4: Diurnal variation of monthly-average hourly relative humidity for Yola

(ii) Weather, Bin data and cooling systems

The bin data compiled for ambient temperature and relative humidity are shown in Figures 5 and 6, respectively, for both locations.

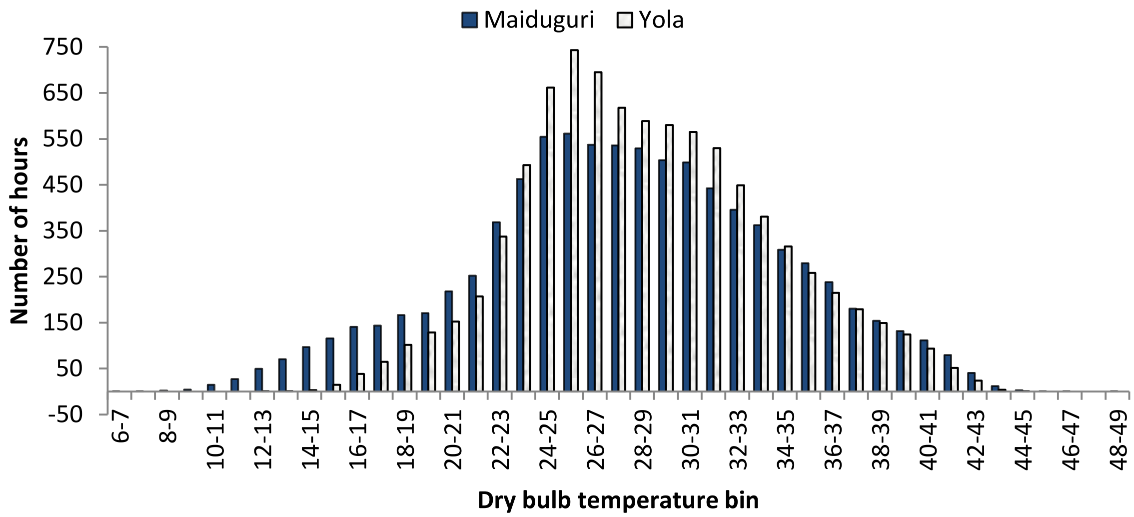

Figure 5: Comparison of Maiduguri and Yola dry bulb temperatures bins

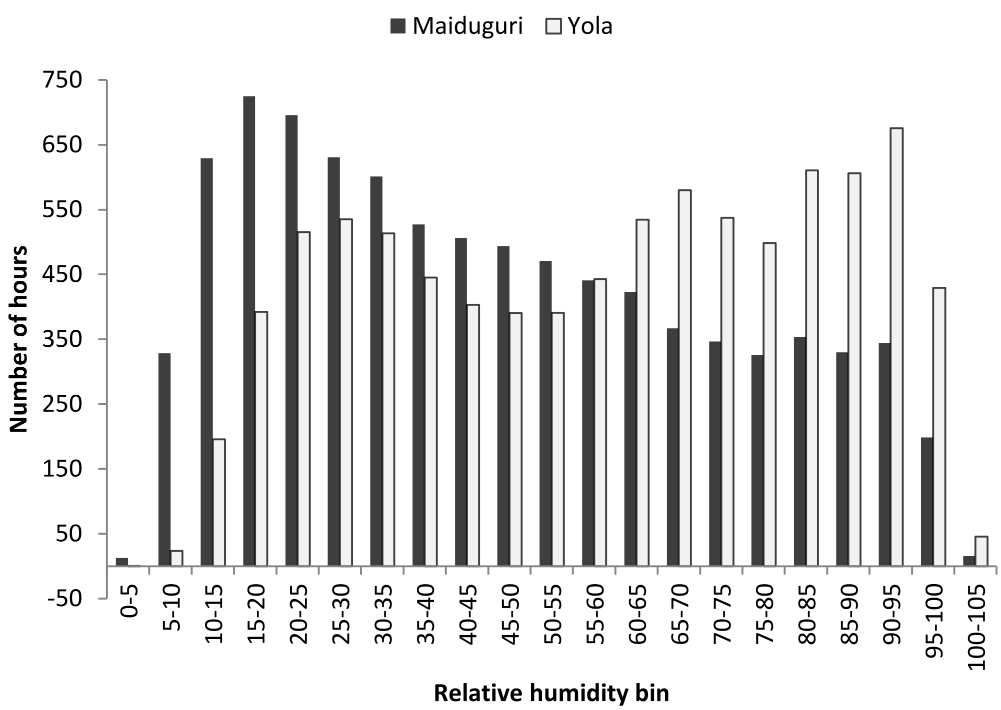

Figure 6: Comparison of Maiduguri and Yola relative humidity bins

From Figure 5 the minimum dry bulb temperature for Maiduguri is in 6-7°C bin at an average of 0.07 hours per year in January during harmattan season, and minimum temperature for Yola occurred in 12-13°C bin for an average of 0.07 hours in November. The maximum dry bulb temperature occurs in 48-49°C bin for an average of 0.07 hours per year and 44-45°C bin for an average of 0.57 hours per year, for Maiduguri and Yola respectively. The modal temperature for the two locations occurred in 25-26°C bin. The minimum and maximum temperatures are two extremes which fortunately occur for few hours per year, otherwise this would have posed a great challenge for human comfort.

The charts in Figure 6 for relative humidity bins for Maiduguri and Yola show that 15-20% RH bin and 90-95% RH bin are the modes for Maiduguri and Yola with 725.02 hours and 675.41 hours respectively. The charts show that most of the time when Maiduguri was dry Yola was relatively humid. The ambient air condition will be outside comfort zone about 2930 hours in Yola when compared to 1725 hours in Maiduguri and there is need for dehumidification to achieve comfort most of the time in Yola.

Tables 1 and 2 show respectively the two-dimensional dry bulb temperature/relative humidity bin data of Maiduguri and Yola. The number in each cell is the average number of hours in a year that dry bulb temperature and relative humidity combination are in the bin. The two-dimensional dry bulb temperature/ relative humidity bin data show the coincidence and distribution of dry bulb temperature and relative humidity. This bin data is useful for accurate estimation of building cooling loads.

Table 1: Two dimensional dry bulb temperature/relative humidity bin data for Maiduguri

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																					
6-7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.07	0.47	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.27	0.73	0.40	0.33	0.14	0.00	0.00	0.00	0.00	0.00	0.00
9-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.20	0.87	1.20	0.80	0.33	0.40	0.33	0.00	0.00	0.00	0.00	0.00	0.00
10-11	0.00	0.00	0.00	0.00	0.00	0.07	0.20	0.40	1.33	2.67	3.73	2.87	1.13	1.13	0.60	0.40	0.00	0.00	0.00	0.00	0.00
11-12	0.00	0.00	0.00	0.13	0.07	0.13	0.07	0.93	3.40	6.47	8.13	4.07	2.27	1.53	0.07	0.13	0.00	0.07	0.00	0.00	0.00
12-13	0.07	0.00	0.00	0.00	0.20	0.33	1.80	3.60	8.53	10.87	11.00	6.40	4.67	1.66	0.33	0.07	0.07	0.00	0.00	0.00	0.00
13-14	0.00	0.00	0.00	0.00	0.47	0.93	2.67	8.27	12.80	15.73	12.60	10.87	4.47	1.13	0.46	0.07	0.00	0.00	0.00	0.00	0.00
14-15	0.00	0.00	0.00	0.13	0.73	1.80	6.60	14.00	21.00	21.13	14.13	11.33	3.67	1.40	0.40	0.20	0.00	0.07	0.00	0.07	0.00
15-16	0.00	0.00	0.00	0.13	1.27	4.27	11.80	19.46	23.26	23.33	16.73	10.80	3.33	1.07	0.20	0.13	0.00	0.00	0.00	0.00	0.00
16-17	0.00	0.00	0.07	0.40	2.60	9.26	19.06	22.66	25.06	25.80	21.53	9.20	3.87	0.93	0.60	0.00	0.00	0.00	0.00	0.00	0.00
17-18	0.00	0.00	0.20	1.27	4.47	12.40	25.71	25.86	23.53	22.00	15.27	8.13	2.67	1.40	0.47	0.00	0.07	0.00	0.00	0.00	0.00
18-19	0.00	0.00	0.07	1.79	9.40	19.00	30.19	30.20	28.26	20.20	14.73	5.33	3.80	1.27	0.87	0.47	0.40	0.40	0.07	0.00	0.00
19-20	0.00	0.13	0.27	3.53	12.40	24.33	31.80	31.26	23.86	17.60	11.20	6.67	3.33	1.40	1.34	0.93	0.67	0.20	0.07	0.00	0.00
20-21	0.07	0.07	1.00	6.80	22.33	35.79	34.79	31.33	24.47	16.67	11.87	7.42	5.02	3.22	2.01	1.34	2.71	1.64	2.39	6.28	0.93
21-22	0.00	0.07	2.00	9.86	25.53	35.66	33.20	26.26	17.73	13.93	9.37	4.24	5.44	3.98	3.94	3.34	4.99	7.73	15.22	26.81	3.09
22-23	0.00	0.33	2.20	14.93	35.72	41.40	36.20	23.53	19.07	12.38	7.03	7.39	6.84	6.79	5.66	8.57	14.16	21.69	46.36	52.61	5.37
23-24	0.07	0.53	4.27	21.33	38.39	47.33	33.26	21.33	12.93	10.17	7.58	6.44	6.74	8.64	10.88	17.38	30.84	51.96	88.81	42.68	1.27
24-25	0.20	0.20	6.13	28.86	47.06	44.73	33.00	17.67	12.61	8.88	7.54	7.86	8.11	11.93	17.65	36.07	62.02	87.72	88.83	26.77	0.98
25-26	0.27	0.40	12.13	34.33	48.13	42.60	27.87	16.27	9.94	6.69	6.49	8.08	13.50	19.17	37.81	58.22	82.14	73.36	48.58	14.60	0.68
26-27	0.20	1.34	15.47	42.06	44.73	35.86	24.34	13.80	8.87	7.61	7.90	12.29	23.87	36.33	54.05	65.33	74.71	40.08	19.19	8.63	0.40
27-28	0.07	1.93	22.46	48.66	47.13	31.67	21.40	11.53	8.07	8.50	14.07	25.50	41.29	49.67	69.99	60.64	38.96	17.02	10.43	6.19	0.34
28-29	0.20	3.53	29.06	53.39	43.27	31.33	17.34	9.87	10.16	15.52	25.05	38.58	55.55	58.96	58.86	38.36	16.83	10.82	8.60	3.84	0.54
29-30	0.27	6.80	35.59	55.13	38.73	22.01	16.73	10.41	12.49	18.71	37.37	51.25	56.36	59.81	41.49	16.46	9.65	6.60	5.66	1.78	0.34
30-31	0.60	11.46	49.12	59.60	37.73	21.47	16.15	12.01	14.79	32.19	43.65	49.18	62.33	49.59	17.78	6.07	5.45	3.15	3.55	2.34	0.55
31-32	0.27	13.20	47.19	51.33	30.13	18.15	11.74	12.22	21.04	37.14	44.27	53.53	54.79	23.33	8.43	4.89	3.52	2.60	2.10	2.29	0.28
32-33	0.60	16.93	51.06	45.73	28.67	15.20	10.40	14.29	31.01	38.77	43.68	46.06	28.52	10.23	4.91	2.92	2.00	2.13	1.59	1.03	0.21
33-34	1.07	21.33	55.19	47.80	26.20	11.94	11.68	19.80	36.99	39.67	37.72	26.05	10.75	5.08	3.73	1.69	1.49	1.16	1.92	0.97	0.21
34-35	0.67	22.46	48.93	41.87	24.67	11.21	15.84	30.37	35.48	31.14	21.35	10.60	5.47	2.65	1.42	0.68	1.23	0.68	0.62	0.75	0.28
35-36	0.40	27.26	49.80	35.53	22.80	13.87	24.29	33.43	31.79	17.47	9.82	5.03	2.39	1.61	0.60	0.75	1.10	0.41	0.35	0.27	0.14
36-37	0.26	29.93	45.13	31.60	17.27	13.75	31.85	35.57	17.99	6.12	3.04	1.74	1.02	1.42	0.61	0.20	0.21	0.20	0.27	0.33	0.00
37-38	1.26	27.73	34.93	21.87	14.88	18.91	29.78	18.63	5.98	2.42	1.27	1.27	0.40	0.47	0.46	0.07	0.07	0.20	0.00	0.07	0.07
38-39	1.27	34.06	30.67	17.27	14.15	22.86	21.68	7.23	1.67	1.27	0.67	0.27	0.53	0.07	0.07	0.19	0.00	0.00	0.00	0.00	0.07
39-40	1.33	32.60	25.00	12.34	20.03	21.93	12.03	3.14	1.40	0.93	0.47	0.13	0.00	0.13	0.20	0.07	0.00	0.00	0.00	0.07	0.00
40-41	1.53	30.60	28.07	14.54	18.15	12.35	4.61	1.07	0.13	0.13	0.07	0.13	0.00	0.13	0.07	0.00	0.00	0.00	0.07	0.00	0.00
41-42	1.66	24.40	18.40	13.61	12.41	5.20	2.53	0.60	0.20	0.27	0.07	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42-43	0.27	13.74	10.40	8.07	4.80	2.40	0.53	0.00	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43-44	0.07	5.93	3.61	1.07	0.93	0.33	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44-45	0.07	1.47	0.73	0.07	0.26	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45-46	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
46-47	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47-48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48-49	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2: Two dimensional dry bulb temperature/relative humidity bin data for Yola

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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
13-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.07	0.40	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14-15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.27	0.13	1.13	0.47	0.53	0.20	0.07	0.00	0.00	0.07	0.00	0.00
15-16	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.33	0.40	1.13	3.20	3.00	2.47	1.40	1.00	0.80	0.67	0.13	0.00	0.00	0.00
16-17	0.00	0.00	0.00	0.00	0.00	0.07	0.20	0.87	1.53	3.27	5.73	6.67	6.67	4.47	4.47	2.53	1.27	0.60	0.00	0.00	0.00
17-18	0.00	0.00	0.00	0.00	0.00	0.33	0.73	2.13	4.13	8.00	7.87	8.40	9.20	6.73	7.40	5.07	3.20	1.00	0.40	0.07	0.00
18-19	0.00	0.00	0.00	0.00	0.13	0.93	2.20	4.67	7.67	13.73	14.80	10.73	11.40	12.20	9.13	6.27	5.00	2.33	0.33	0.00	0.00
19-20	0.00	0.00	0.00	0.07	0.33	1.73	5.47	11.80	12.47	15.93	16.40	15.40	15.07	10.93	8.33	7.13	4.20	2.07	1.13	0.13	0.00
20-21	0.00	0.00	0.07	0.47	1.40	5.47	10.60	11.07	20.40	18.13	13.67	14.07	16.67	12.07	9.33	6.20	5.47	3.13	1.87	1.69	0.54
21-22	0.00	0.00	0.07	0.80	3.07	10.80	16.86	19.33	19.60	20.33	17.40	14.87	13.80	12.80	8.20	5.47	5.67	6.01	6.52	18.63	6.82
22-23	0.00	0.00	0.00	1.20	5.87	14.47	20.40	20.40	30.47	13.80	17.67	15.80	12.20	8.80	8.73	7.13	10.42	11.13	37.21	85.44	16.15
23-24	0.00	0.00	0.07	1.47	6.13	18.29	23.74	27.87	21.80	19.21	14.87	14.87	9.73	7.94	6.67	11.61	17.34	40.49	117.64	122.44	10.73
24-25	0.00	0.07	0.41	2.67	8.26	21.29	31.87	25.10	22.63	14.87	14.23	10.53	9.60	9.09	9.41	14.25	39.84	105.74	202.35	115.19	4.21
25-26	0.07	0.00	0.40	3.00	13.73	30.07	29.36	31.27	19.44	16.76	10.87	9.74	9.87	10.16	12.26	27.85	104.63	174.62	184.49	52.36	2.20
26-27	0.00	0.13	0.40	4.61	17.89	29.90	38.08	25.86	16.62	14.92	9.57	9.50	9.25	15.70	32.16	63.82	163.63	139.42	84.83	17.65	1.20
27-28	0.00	0.00	0.67	7.47	21.38	34.50	33.72	25.43	14.75	10.31	9.99	9.26	14.84	23.66	63.36	104.04	141.72	73.85	21.66	6.27	0.80
28-29	0.00	0.07	1.41	10.81	28.49	36.52	36.16	19.67	15.02	11.33	8.61	12.14	29.75	47.39	106.81	116.34	67.19	30.05	7.42	3.08	0.60
29-30	0.00	0.22	2.50	13.62	34.14	34.75	29.40	22.71	13.45	9.43	12.45	27.76	42.90	96.34	124.45	78.89	24.59	6.97	2.93	2.20	0.40
30-31	0.00	0.00	3.81	20.06	40.88	38.67	27.21	18.53	11.42	11.63	19.44	41.32	69.94	139.50	79.97	26.62	7.48	3.88	2.27	1.87	0.47
31-32	0.00	0.07	6.87	30.63	39.25	37.17	28.33	14.94	9.89	16.10	29.78	52.31	109.04	107.14	31.70	7.95	3.20	1.47	2.40	1.00	0.60
32-33	0.00	0.27	8.74	31.49	45.13	37.15	24.81	12.35	11.54	20.14	35.24	70.92	95.63	37.01	9.23	3.76	1.80	1.33	1.15	0.87	0.40
33-34	0.00	0.61	11.78	38.92	46.48	31.23	20.86	14.04	16.59	29.40	53.48	62.01	36.86	12.30	2.53	1.00	1.14	0.47	0.47	0.27	0.27
34-35	0.00	0.75	14.58	39.12	42.49	32.35	20.17	18.40	23.80	39.07	46.72	26.04	6.77	2.28	0.74	0.74	0.74	0.49	0.28	0.21	0.07
35-36	0.00	1.28	18.98	38.52	39.11	26.57	17.10	16.61	27.74	41.32	22.56	5.69	1.21	0.33	0.13	0.21	0.56	0.15	0.14	0.00	0.00
36-37	0.00	1.29	18.59	33.55	33.66	19.71	17.55	24.33	31.02	27.82	4.86	0.48	0.28	0.20	0.22	0.22	0.56	0.35	0.07	0.00	0.00
37-38	0.00	1.99	19.70	32.44	22.07	15.53	16.93	26.16	31.60	10.51	0.55	0.00	0.13	0.21	0.47	0.49	0.20	0.07	0.00	0.00	0.00
38-39	0.00	2.45	24.60	24.46	16.29	12.74	20.88	28.17	14.86	2.56	0.56	0.20	0.07	0.42	0.50	0.20	0.00	0.07	0.07	0.00	0.00
39-40	0.07	3.68	22.37	21.17	16.71	16.05	22.16	16.83	4.00	0.21	0.07	0.07	0.28	0.35	0.07	0.07	0.07	0.00	0.00	0.00	0.00
40-41	0.00	4.27	19.49	17.43	15.30	17.98	13.54	4.69	0.27	0.07	0.21	0.00	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
41-42	0.00	4.17	11.10	10.84	11.01	7.56	4.61	1.49	0.40	0.13	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42-43	0.00	1.66	8.46	5.36	4.99	2.77	0.36	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43-44	0.00	0.28	0.36	1.77	0.99	0.36	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44-45	0.00	0.00	0.07	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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(iii) Evaporative cooling

When a place has dry bulb temperature equal to or higher than 32.2°C with coincident relative humidity of less than 50%, there will be appreciable evaporative cooling.

The number of hours in each month for both locations in which a high level of evaporative cooling could occur (dry bulb temperature ≥ 32.2°C with relative humidity ≤ 50%) are shown in Figure 7.

From Tables 1 and 2, the number of hours for T_{DB} and RH within these ranges for both Maiduguri and Yola are shown inside the lower rectangles and the total number of hours are1978.34 and 1686.68 hours respectively for Maiduguri and Yola. These figures compare well with results obtained from the addition of monthly average number of hours for Maiduguri and Yola in Figure 7.

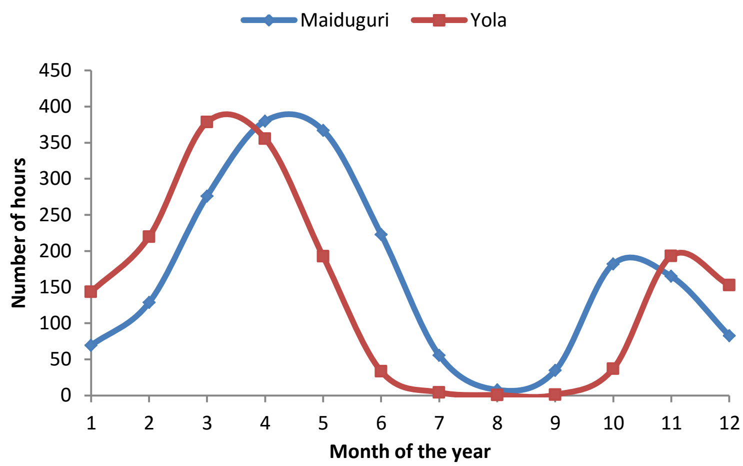

Figure 7: Number of hours in which a high degree of evaporative cooling can take place

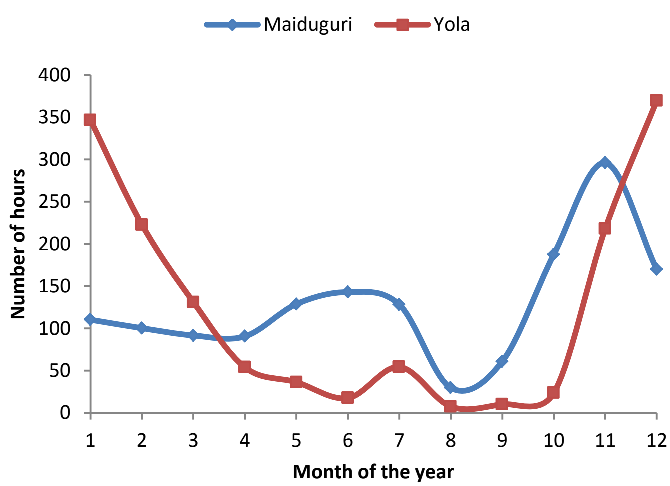

Figure 8: Number of hours in which the weather is within the comfort zone

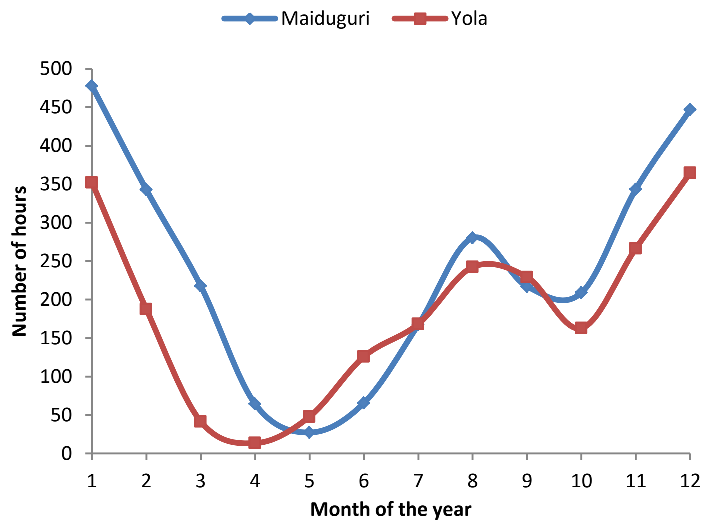

Figure 9: Number of hours in which the dry bulb temperature is less than 25°C

(iv) Comfort zone and ventilation

The average number of hours in the year in which the weather condition lies within the comfort zone is the addition of the hours bounded by the upper rectangles in Tables 1 and 2 and the totals are 1498.04 and 1449.03 hours for Maiduguri and Yola respectively. The monthly number of hours of this is shown Figure 8 for both locations which added up to be 1498.05 and 1448.48 hours for Maiduguri and Yola respectively. The small differences (1498.05 – 1498.04) and (1448.48 – 1449.03) are due to computational errors. October, November and December are the three months having highest number of hours per month in the comfort zone for Maiduguri. While the four months with highest number of hours per month in the comfort zone for Yola are November, December, January and February; these months are in the hammattan season for Yola. In Maiduguri, August and September have the lowest number of hours in the comfort zone. While the lowest number of hours in the comfort zone for Yola occur in August to October.

When weather is within the comfort zone, only ventilation is needed for human comfort which could be achieved by natural breeze or fans driven by electric motor. Air conditioning systems will be expected to work for the highest number of hours and thus consume highest amount of energy per month in the months of August and September for Maiduguri and Yola respectively, since they have the lowest number of hours in the comfort zone. On the other hand, the cooling units are expected to work for minimum number of hours for December and January in Maiduguri and October and November in Yola, leading to minimal energy consumption.

Figure 9 shows the number of hours in each month in which dry bulb temperature is less than 25°C for both cities. Since the indoor design dry-bulb temperature for comfort air conditioning systems is 24°C, the hours having dry-bulb less than 25°C are the hours in which it is not necessary to put on an air conditioner.

The transmission heat gain resulting from temperature difference between the outside air and the air in the space being cooled and air change heat gain due to door opening and infiltration are important components of the cooling load of a cooling system. The numbers of hours when the ambient temperature is above 25°C can be used as an indicator of the magnitude of these heat gains. From Figure 9, the refrigerator can be expected to consume minimum energy per months in the months of December and January at both Maiduguri and Yolaand maximum energy in May and April at Maiduguri and Yola respectively.

4. Conclusions

Dry-bulb temperature and relative humidity data for Maiduguri and Yola have been analysed to produce one dimensional bin data for both variables and also T_{DB}/RH two-dimensional bin data. There are higher numbers of hours in the comfort zone in December and January for Yola while the best period for comfort is November for Maiduguri; the two lowest number of hours for comfort zone occur in August and September for the two locations. Evaporative coolers will work best at both Maiduguri and Yola from March to May. The poorest performance of evaporative cooler will occur from July to September. From October to February, the monthly cost of running refrigerators and air conditioners will be lowest compared to other months of the year since these are months having low RH and also low T_{DB}.

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