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Weather Data Analysis for Outdoor Design Conditions for Air Conditioning Systems in Selected Cities in South-West Nigeria

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Abstract:
Weather data is a challenge for designing an air-conditioning system around the globe. The acquired hourly meteorological data for relative humidity and dry-bulb temperature for Abeokuta, Ibadan, Ikeja, Ondo, and Oshogbo, covering the period from 2013 to 2022, were digitised using Microsoft Excel. The digitised data were analysed to provide the appropriate outdoor design conditions of 1%, 2½% and 5% outdoor design temperature of the four warmest months, for the temperatures of dry and moist bulbs, and 0.4%, 1%, and 2% outdoor design temperature of the cumulative distribution function with their corresponding coincident relative humidity. The results of this study will provide updated information on outdoor design conditions for the selected South West cities in Nigeria, which will be useful for other locations in their proximity.

Keywords — Air conditioning, climate change, energy efficiency, design conditions, outdoor condition

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I. INTRODUCTION

When it comes to building systems, especially HVAC (heating, ventilation, and air conditioning) applications, to be designed effectively, precise descriptions of external air conditions, relative humidity and dry bulb temperature are crucial [1]. In the Western political region of Nigeria, climate plays an important role in thermal comfort energy demands and performance in building envelopes, so the need for localised and reliable weather conditions is of Paramount importance.

Most of the design in this region relied on generic or outdated climate data, which would result in potential inefficiencies and suboptimal system performance [2]-[3]. It has been realised from recent studies that there is an increase in the cooling need resulting from an increase in ambient temperatures from climate change impacts [4]. This study is considering an updated statistical analysis of whether parameters such as dry bulb temperature, relative humidity collected from selected locations in Western Nigeria and wet bulb temperatures developed from the duo. This is aimed at developing robust outdoor air condition profiles which would be standards or codes useful for HVAC designers, urban planners and builders in making factual data-based decisions geared to the region's microclimates realities.

In this study, statistical techniques which include percentile ranking, four warmest months and bin data development were employed so as to derive representative design conditions and annual profiles [5]. The results that would be obtained will be good to support and improve HVAC designing in the sizing of system energy modelling and climate-responsive architectural design [6] [7]. In the long run, the study will contribute broadly to energy efficiency, thermal comfort and environmental sustainability in building practices within Western Nigeria's tropical climate [8].

Climate data analysis is a crucial necessity in building design, particularly for HVAC (heating, ventilation, and air conditioning). In engineering practice worldwide, the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has developed international standards for climate design conditions in a variety of places [1]. The ASHRAE standard 169-2021 on climate data for building design standards makes provision for a comprehensive guide for determining appropriate outdoor design conditions [9]. It is equally important that localised climatic variations are necessary for region-specific studies to ensure accuracy in design and energy modeling, particularly in tropical environments [10].

Several studies have emphasised the importance of detailed meteorological data for HVAC design and thermal comfort modelling. Passive design strategies in Nigeria and the limitations of using generalised climate data for region-specific application were done by Ogbonna and Harris [11], whose work investigated thermal comfort in sub-Saharan Africa for the provision of indoor environmental conditions for naturally ventilated buildings. Equally, Nigeria's climate zone and proposed classifications relevant to building design were done by Adebayo [12], with more recent work by Ogunsote and Prucnal-Ogunsote [13] and Mobolade and Pourvahidi [8] who defined these classifications using bioclimatic approaches. This study underscores the diversity of Nigeria's climate and the need for microclimatic assessment.

In recent years, several studies were carried out by the authors and others (Awolola et al) on degree days analysis, frequency distribution and percentiles ranking for assessing climatic conditions for energy modelling purposes [2]. This work supports the trends towards data-driven HVAC design, which emphasises location's specific climatic parameters such as dry bulb temperature and relative humidity patterns. The bin data method is a simplified and widely adopted energy consumed estimation method and heating and cooling loads based on climate data, and these have been extensively documented [5]. This involves dividing a year's temperature data into discrete intervals or bins of about 1°C increments. Each bin represents a range of outdoor air temperature, and the number of hours per year that fall within each temperature bin is counted. The bin method can be used in two dimensions of temperature and relative humidity, which shows how both bulb temperature and relative humidity occur simultaneously.

Earlier works on weather data analysis in eighteen Nigerian locations were done. This involves grouping temperature data into intervals for air conditioning design methods. The earlier works include locations in south-west Nigeria but did not include Abeokuta and Osogbo, and the data were based on the first decade of the twenty-first century [14]-[15].

There is a gap in the existing research which this study focuses on by doing the statistical analysis of the outdoor air conditioning data set for five cities in Western Nigeria, such as Ibadan, Ikeja, Osogbo, Ondo and Abeokuta, using 10-year data from 2013 to 2022. Acknowledging the increasing ambient temperatures globally due to climate change [16]-[17], and the significant increase in cooling requirements observed in tropical cities like Lagos [4] [18], there is an urgent need to update outdoor design conditions. In recent times, researchers have highlighted that energy-efficient building design tailored to Nigeria's diverse climatic conditions is essential for achieving economic and environmental sustainability [2][3][8]. The importance of optimising residential indoor thermal environments through passive design and mechanical ventilation in tropical savanna climate zones, such as those found in Nigeria, was established by [6].

The study aims to analyse weather data for outdoor design conditions for air conditioning systems in five selected cities in the South-West, Nigeria, through the following objectives;

a. Evaluate the 1%, 2½% and 5% outdoor design dry bulb temperature (TDB) and corresponding wet bulb temperature (TWB) computed from a combination of dry bulb temperature (TDB) and relative humidity of the four warmest months.

b. Computing the probability density function (PDF) and cumulative distribution function (CDF) for the dry bulb temperature (TDB) and then

c. Determine 0.4%, 1% and 2% upper percentiles from the bin data of TDB and then the coincident relative humidity.

II. MATERIALS AND METHOD

A. Study Area

The meteorological weather analysis is based on five cities of the South-West geopolitical zone of Nigeria. The cities are the capitals of four states, and one is a prominent town of a state. The following are the cities with their locations on the globe: Ibadan, the capital city of old western region and capital of present day Oyo state is located on latitude 7o23’16’’N, longitude 3o53’47’’E, Ikeja, the capital city of Lagos state is located on latitude 6o40’N, longitude 3o20’E, Abeokuta is the capital city of Ogun State and is located on latitude 7o09’20.56’’N, longitude 3o20’42.32’’E, and Oshogbo, the capital city of Osun state is located on latitude 7o45’59.99’’N, longitude 4o33’59.99’’E, while Ondo, a prominent town on Ondo State is located on latitude 7o5’59’’N, longitude 4o49’59’’E. These cities are shown in the Map of Nigeria in Figure 1.

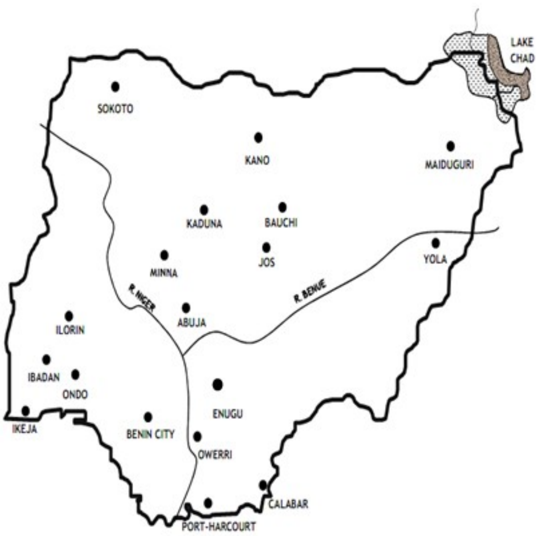

Figure 1: Map of Nigeria showing the locations

B. Data Collection

The Nigerian Meteorological Agency (NiMet) provided hourly dry-bulb temperature and relative humidity data using NIMET form 131/3, obtained from automatic graphical records or eye recordings, for the period 2013 to 2022. For the ten years under consideration, the meteorological parameters were recorded hourly for twenty-four hours every day for 28-day, 30-day, or 31-day months, as applicable.

C. Data Digitalization

Since these data were obtained via forms, there is a need to digitise them for analysis. It is such a large data set. The data were imputed on the computer with the spreadsheet - Microsoft Excel software package version 2010. A file was dedicated to each city, with 24 sheets: 12 for dry-bulb temperature and 12 for relative humidity. On each sheet, the data were arranged hourly on columns and days on rows. Each sheet contains ten years of data for a particular month. These imputed data were checked for errors, and the concreteness of these data was validated before analysis.

D. Data analysis

The four warmest months for each location were determined by calculating the monthly average temperature of each location. The four months with the highest averages were known, and the four warmest months, the design month had the highest average dry bulb temperature. Using the hourly relative humidity and dry-bulb temperature, the 3-hourly values of 0, 3, 6, 9, 12, 15, 18 and 21 hours of the wet-bulb temperature were evaluated using the *Stull* equation to compute approximate wet-bulb temperatures. The formula is as stated below: wet-bulb temperatures. The formula is as stated below:

$$T_{WB} = T_{DB} * \tan^{-1}(0.051977)\sqrt{RH + 8.313659} + \tan^{-1}(T_{DB} + RH) - \tan^{-1}(RH - 1.676331) + 0.00391838 * \sqrt{RH} * \tan^{-1} 0.023101RH - 4.686035$$

Where T_{WB} = Wet bulb temperature, TDB = Dry bulb temperature and RH = Relative humidity.

These values were obtained for 3-hourly wet bulb temperatures for the four warmest months of the five locations. The average monthly dry bulb temperature, standard deviation, and daily range

were computed. The 1%, 2½%, and 5% confidence values for dry bulb temperature using the monthly mean values and standard deviations for the four warmest months were determined with the Normal or Gaussian Distributions statistical Tables. This was equally applied to the evaluated 3-hourly wet bulb temperatures.
The cumulative distribution function (CDF) and probability density function (PDF) were created, and a bin width of 1°C was chosen. Then the 0.4%, 1.0% and 2% upper percentile dry bulb temperature values were found for each location from the cumulative distribution function (cdf) curves from the developed cumulative distribution curves for each of the locations. Then, the coincident relative humidity (CRH) for each percentile of the dry bulb temperatures was obtained with Visual Basic codes with data retrieved from the Microsoft Excel package.

III. RESULTS AND DISCUSSION

Table 1 shows the 1%, 2½% and 5% outdoor design dry bulb temperature (TDB) and corresponding wet bulb temperature (TWB) computed from a combination of dry bulb temperature (TDB) and relative humidity (RH) of the four warmest months in Table 2.

Table 1: Four warmest months for Outdoor Design Conditions for Air Conditioning Systems in
Selected Cities, South West, Nigeria.

Locations	Abeokuta	Ibadan	Ikeja	Ondo	Osogbo
Design month	February	February	March	February	March
	Degree Celsius	Degree Celsius	Degree Celsius	Degree Celsius	Degree Celsius
Outdoor daily range	22.5	21.1	20.8	22.5	23.7
1%	37.0	36.4	35.4	36.4	36.4
2.5%	35.7	35.1	34.3	34.9	34.9
5%	34.5	33.9	33.4	33.7	33.7
Mean	28.8	28.2	28.5	27.5	27.5
Standard Deviation	3.5	3.5	3.0	3.8	3.8

Table 2: Wet bulb four warmest months for Outdoor Design Conditions for Air Conditioning Systems in Selected Cities, South West, Nigeria

Locations	Abeokuta	Ibadan	Ikeja	Ondo	Osogbo
Design month	February	February	March	February	March
	Degree Celsius	Degree Celsius	Degree Celsius	Degree Celsius	Degree Celsius
1%	29.4	32.0	29.6	29.0	28.9
2.5%	28.7	30.4	28.9	28.1	28.1
5%	28.1	28.1	28.1	28.1	28.1
Mean	25	22	25.6	23.2	24
Standard Deviation	1.9	4.3	1.7	2.5	2.1

Figures 2 to 6 give the cumulative distribution curves for each location.

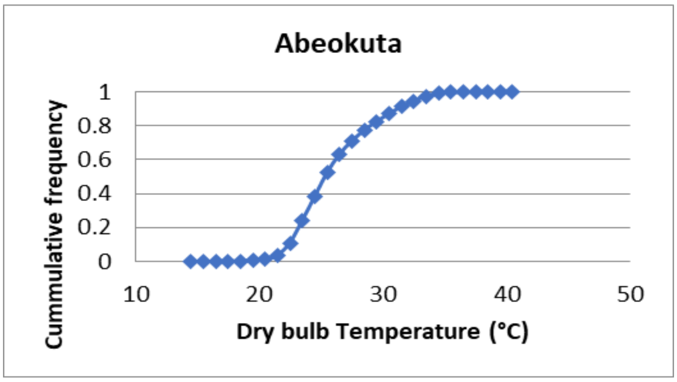

Figure 2: Cumulative distribution curves for Abeokuta

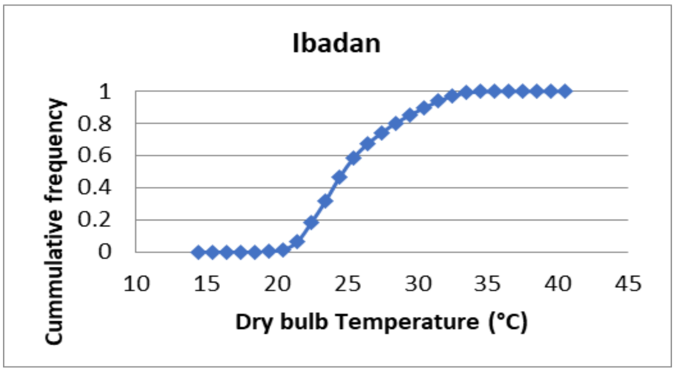

Figure 3: Cumulative distribution curves for Ibadan

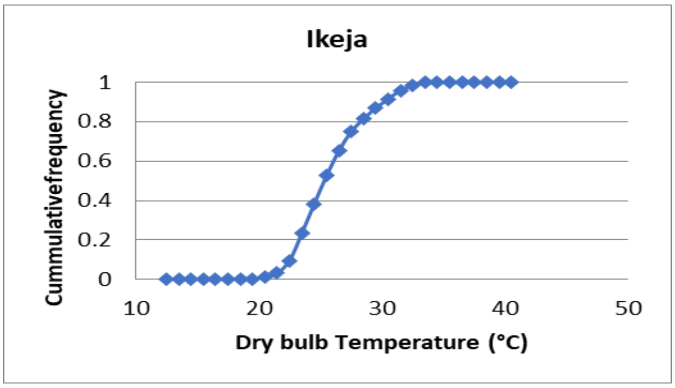

Figure 4: Cumulative distribution curves for Ikeja

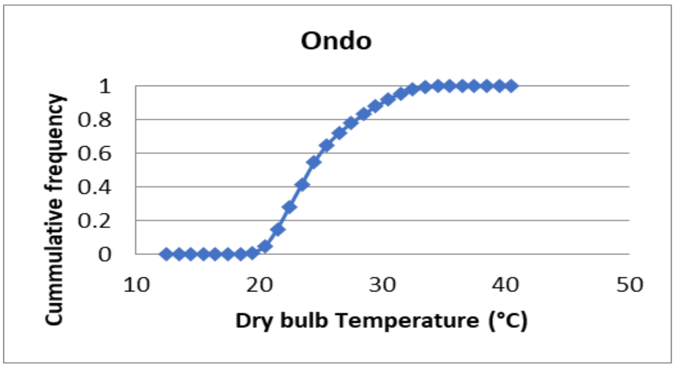

Figure 5: Cumulative distribution curves for Ondo

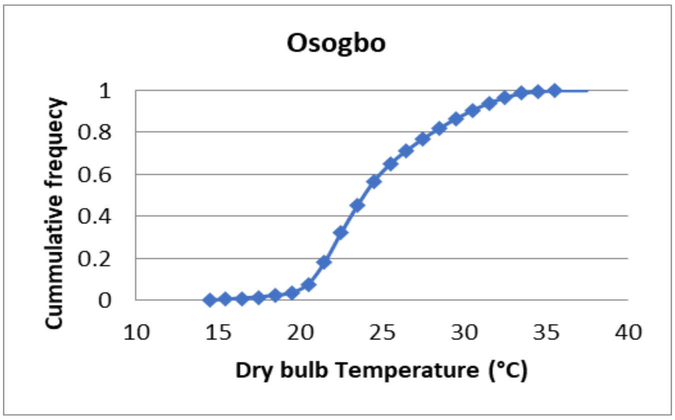

Table 3 shows the results obtained from the 0.4%, 1% and 2% upper percentiles from the bin data of TDB and then the coincident relative humidity.

Table 3: The upper 0.4%, 1% and 2% percentile from the bin data of dry bulb temperature and the coincident relative humidity.

City	Abeokuta		Ibadan		Ikeja		Ondo		Osogbo	
	Degree Celcius	CRH (%)	Degree Celcius	CRH (%)	Degree Celcius	CRH (%)	Degree Celcius	CRH (%)	Degree Celcius	CRH (%)
0.4%	34.0	47	33.0	48	33.0	62	32.0	57	33.0	49
1%	33.0	56	32.0	54	32.0	65	31.0	53	32.0	53
2%	32.0	59	31.0	59	31.0	69	30.0	66	31.0	61

From Table 1, our study on the four warmest months for outdoor design conditions for air conditioning systems in the selected locations found that the design month for Abeokuta, Ibadan, and Ondo is February, while that for Ikeja and Oshogbo is March. The highest mean temperature occurs in Abeokuta, and the lowest occurs in both Ondo and Oshogbo. For wet bulb temperature, the highest occurred in Ikeja during the warmest month, which is mainly factored on the humid conditions of the Lagos environment. The lowest is in Ibadan. These outcomes of the design months are in tune with the earlier finding by Olorunmaiye and Awolola (2017) for Ibadan, Ikeja and Ondo in the earlier studies. However, there is a slightly higher temperature profile for Ibadan and Ikeja, but Ondo has slightly lower temperatures. These suggest a change in the ambient temperatures over the years. The data for this study is just for a period of ten years, while the earlier study was for 15 years.

The implication of using the four warmest months data sets is that HVAC system design is based on the real worst demand period, but not just on statistical extremes. This is more appropriate, which helps with the right sizing of the system. This ensures system optimisation for when cooling is needed, not considering the rare worst-case periods. The utilisation of this data set for design will improve operational efficiency and reduce cycling losses, because the system design will meet real occupant comfort needs during the warmest months. This method could allow for passive cooling strategies such as shades or night ventilation.

From Figure 2 (a) to (e) and Table 3, the results obtained from the cumulative distribution function developed from bin data for 0.4%, 1% and 2% upper percentile showed that Ondo has 32ºC for 0.4% percentile which is the lowest and Abeokuta has 34ºC which is the highest and others, Ibadan, Ikeja and Oshogbo has 33ºC, these values give the temperature for 35 hours of the 8760 hours of the year. These results are equally has slightly deviations from what has been computed from 1995 - 2009 data (Olorunmaiye and Awolola, 2017) for Ibadan which was 36ºC for 0.4%, 35ºC for 1% and 34ºC for 2%, Ikeja which was 34.2ºC for 0.4%, 35.6ºC for 1% and 33.2ºC for 2%, and Ondo which was 35.4ºC for 0.4%, 34.5ºC for 1% and 33.6oC for 2%. Heating Ventilation Air Conditioning (HVAC) designers use extreme design conditions so as to ensure that the air conditioning system has the capacity to handle rare and severe heat events. It is believed that 1% and 2% values are for less conservative heat, but reliable sizing for economy and performance. If 2% value for design, the performance during the hotter period may be hampered, therefore affecting comfort. On the other hand, designing using the 0.4% percent condition gives better resilience but may result in over-sizing, resulting in higher capital cost and likely lower efficiency under normal conditions due to part-load operation. Space designed using 2% percentile is likely to maintain comfort most of the year, but there is a likelihood of the need for supplementary cooling. These percentile temperatures align with the ASHRAE design guideline, which recommends the use of percentile-based design dry bulb temperature for cooling system designs.

From the results obtained for coincidence relative humidity RH at 0.4% upper percentile for Abeokuta, it is 62% at 1% and 2% RH is higher in Ikeja and Ondo, with 65-69% compared to that of Abeokuta's 56-59%, this implies higher combined heat and moisture loads on coastal-influenced locations.

For general HVAC design, 1% dry bulb temperature is desirable or recommended for most applications, while 0.4 is suitable for critical facilities. With high RH in Ikeja and Ondo, there is a need to do dehumidification. Oshogbo and Ondo can key into the possibility of passive cooling. There is a need to do efficient mechanical cooling in Abeokuta, and good humidity management is desirable in Ibadan.

IV. CONCLUSION

This study analysed outdoor design conditions for five major locations in south west Nigeria, which are Abeokuta, Ibadan, Ikeja, Ondo and Osogbo, using a ten-year hourly meteorological data. The results of the study have provided reliable design dry bulb temperature and wet bulb temperature with coincidence relative humidity values, which better show the climate realities compared with the 1951-1965 data set still referenced in the existing design codes.

The findings based on the four warmest months analysis showed that the design months differ across the locations, as Abeokuta has February with Ibadan and Ondo, but March is for Ikeja and Osogbo. Abeokuta has the highest average temperature, while Ondo and Osogbo have the lowest mean temperature.

The wet bulb temperature results depicted that a higher humidity level in Ikeja is characterised by it being in a coastal environment, which indicates the need for integrated humidifier systems in HVAC design, which is very useful in coastal and humid inland environments.

The upper percentile analysis from the cumulative distribution function establishes the temperature threshold of system sizing in extreme conditions. There is a gradual temperature rise compared to that of the earlier period, 1995-2009, which suggests an ongoing global warming, which should be a factor in the design update. The 1 per cent design dry bulb temperature remains the most practical choice for general air conditioner applications, while the 0.4 per cent percentile is more appropriate for high occupancy facilities for high reliability.

Equally, the high coincidence relative humidity values have been observed up to 69 per cent in coastal areas, which accounts for the increasing need for humidity control measures such as adopting a Dedicated Outdoor Air Systems (DOAS) and energy recovery ventilation to decouple sensible and latent loads. On the contrary, cities such as Ondo and Oshogbo show the potential for passive cooling schemes due to lower temperature-humidity combinations.

Overall, the study contributes valuable and localised climatic data necessary for accurate load estimation, energy-efficient HVAC system design, and sustainable building operation in Nigeria's tropical space. It is then recommended that these updated parameters be incorporated into future revisions of the Nigerian outdoor design standard and adopted for engineering practice for improved thermal comfort, reduction in energy utilisation, and improved resilience against the influence of climate change.

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