Typical meteorological year data analysis for optimal usage of energy systems at six selected locations in Nigeria

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Abstract

In this study, the typical meteorological year (TMY) data for six locations representing the six geopolitical zones in Nigeria were generated and analyzed using the Sandia method. The analysis shows that seasonal variations exist in all the selected locations indicating two distinct seasons: the dry and wet seasons with varying lengths from north to south of the country. Due to its high global radiation levels (21–25 MJ/m^2/d), the North is a desirable location for solar-thermal systems. In addition, the high monthly mean temperature variations (∼18°C), low relative humidity (RHM) (15%) and constant wind speeds (4 m/s) experienced in the first 3 months of the year aid the installation of wind energy systems and the application of evaporative cooling techniques that reduce the thermal load and energy consumption of buildings. On the other side, the high RHM (80%) and mediocre radiation values derived almost throughout the year in the Southwest, Southeast and South–south regions discourages the extensive application of evaporative cooling and solar energy-based systems in such locations, but the moderate wind speeds (2.9 m/s) and monthly mean temperature variations associated with these regions between the first 3 months of the year allow for the application of natural ventilation and some passive cooling systems so as to reduce the thermal load of buildings in the regions. The information presented in this work can serve as a guide for design and selection of energy systems and application of energy-related projects in Nigeria.

Keywords: thermal load; solar thermal system; relative humidity; wind speed; solar radiation; Energy systems

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1 INTRODUCTION

The continuous depletion of nonrenewable energy resources, air pollution and global warming are all attributed to the existing energy consumption trends [57]. The building sector is responsible for a significant amount of the global energy consumption. Commercial, residential and industrial structures are estimated to absorb between 30 and 50% of the total energy required by civilization, according to Hui *et al.* (1999). In an effort to reduce the negative effects of excessive fossil fuel use in the building sector, renewable energy sources are becoming more and more competitive with fossil fuels [36]. Therefore, selecting a profitable location for the proper harvest of renewable energy sources (wind, solar *etc*) requires accurate meteorological data analysis [31]. It has been demonstrated that the performance of thermal energy systems is primarily determined by the weather [42]. To properly simulate heating, ventilation and air conditioning (HVAC) systems and design solar energy systems, such as solar thermal systems and solar hot water systems for domestic use, it is crucial to have knowledge of weather data, including dew point temperature (DPT), dry-bulb temperature (DBT), relative humidity (RHM), solar radiation and wind speed. An appropriate energy analysis

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that takes heating, cooling and lighting loads into account cannot be done in the absence of meteorological data that accurately represents the climatic conditions [23]. The reason being that this information is crucial for establishing the building's thermal balance in response to shifting climatic conditions and identifying the boundary conditions that have an impact on the functionality of the building's machinery, such as the heating, cooling and ventilation systems [1].

Because weather conditions can vary substantially from year to year, specialized weather data collection that precisely depicts the long-term averaged weather conditions over the course of a year is necessary. Typical year files are widely used in building energy modeling to determine annual energy consumptions [25]. This typical year can be produced in a variety of ways, as various earlier attempts have shown. The method used in this article is the typical meteorological year (TMY) using the Sandia (Finkelstein-Schafer statistical) technique. The TMY is recommended because the months that make up the year—the typical meteorological months (TMMs)—are actual months derived from the available data. The reason is because a simple average of the annual data would underestimate the amount of fluctuation, so a month that is the most representative of the place under examination is chosen [4]. But according to Marion and Urban [32], the TMY is not always a reliable predictor of circumstances for the following year or even the following 5 years. Instead, it represents circumstances that are believed to be common throughout a long period [11]. However, due to the strong diurnal variation in weather parameters, a more constant property such as climate is adopted because climatic parameters are seemingly constant over a long period ([3]; Ebrahimpour and Maerefat [14]). However, the large quantity of data related to climates makes them difficult to be used directly in determining performance of energy systems. Hence, compact and easily interpreted data is generated from the climatic data. This data is called 'typical year'.

TMY refers to a collection of collected data from several past years that depicts the actual hourly meteorological characteristics for a particular region for a period of 12 calendar months (1 year). According to ISO 15927-4:2005 (ISO, 2005), a multiyear of $\geq$10 years should be used to produce a representative TMY [7]. Studies have indicated that records of $\leq$10 years may result in reference years that are less representative. On the other side, it is discovered that the weather files created over longer timescales are less reflective of recent years (and ostensibly of years to come) [30]. Bulut [11] claims that numerous attempts have been undertaken using a variety of approaches to create TMY databases for various regions of the world. Their principal difference is the statistical approach to identify the selection of the most typical data for the construction of the TMY as well as the weather indicators, accuracy and complexity of each method [6]. Some of the most recent methods are the Sandia method; the Danish method; the Festa-Ratto method; the Miquel-Bilbao method, which is based on weather meteorological data and not on solar radiation; Crow method and Gazela-Mathioulakis method. Extensive comparison between these methods has been carried out [6, 14, 24, 47], and the results demonstrated that most of the methods have similar performance. However, the Sandia method is the most widespread approach for the generation of TMY due to its simplicity [24]. The 'Sandia approach' developed by Sandia Laboratories is based on the Filkenstein–Schafer (FS) statistical method.

The development of a TMY is critical for calculations in the field of thermal engineering [39]. The TMY can be used to compare various systems whose performance is affected by weather conditions [34]. As a result, it's critical in evaluating solar and wind energy systems, including photovoltaic systems, as well as building energy efficiency ([44, 52] in Hui, *et al.*, 1999). However, it is impossible to create a year that is typical in all situations because environmental factors and their effects on energy building performance differ (Hui, *et al.*, 1999). The purpose of the TMY is to supply reliable and representative input data because the individual months comprised in the typical year are real months picked from different years. A typical year can be considered as a compromise between using a multiyear dataset and accurately portraying the statistics of long-term weather data, similar to how a synthetic year does [44, 49, 56].

Numerous studies, including ones in Nigeria, have been conducted in various nations to better understand the significance of TMY. For the city of Athens, a TMY was produced in 1988 by Pissimanis *et al.* Using daily sun radiation data from long-term studies, Shaltout and Tadros [45] developed a typical solar radiation year for Egypt. For five cities in Saudi Arabia, Said and Kadry (1994) calculated typical weather years. TMYs were created by Sawaqed *et al.* (2003) for seven different locations in Oman locales. For Nicosia, Cyprus, Petrakis *et al.* (1998) generated a typical year. By Argiriou *et al.*, 20 years' worth of hourly weather readings from Athens, Greece, were subjected to a total of 17 approaches for creating test reference years (TRYs) published in the literature (1999). They demonstrated that the modified Festa-Ratto approach is the TRY that closely resembles the performance of the systems as predicted using long-term data. A new kind of TMY for Nicosia, Cyprus, was presented by Kalogirou [27]. The basic TMY used in the presentation was produced by using the FS statistical approach to accessible hourly meteorological data collected between 1986 and 1992. Using three distinct techniques, Bilbao *et al.* (2004) created TRYs for two cities in Spain: Madrid and Valladolid. Skeiker [48] generated a TMY for Damascus zone using the FS statistical method.

Based on recorded meteorological data, Sawaqed, *et al.* [44] reported on the creation of TMYs for seven different locations in Oman. Rahman and Dewsbury (2007) talked about how TRYs were chosen for Subang, Malaysia, and outlined the procedures for choosing typical weather data. Yang, *et al.* [53] studied and published TMYs for 60 cities in China's five main climate zones (severe cold, cold, hot summer and cold winter; hot summer and warm winter and mild) (2007). The Sandia, Danish and Festa-Ratto methods were used by Janjai and Deeyai [24] to generate TMYs at four meteorological stations in Thailand. They compared the performance of these three TMY generation methods. Jiang [25] carried out the creation of TMY for eight representative cities that represented China's main climate zones. Lee, *et al.* created a set of ISO TRY data for seven locations in Korea (2010).

Table 1. *The Six Selected Locations for Study*

Location	Geopolitical Zone	Latitude (°N)	Longitude (°E)	Elevation (m)
Abuja	Federal Capital Territory	9.24	7.15	244
Akwa—Ibom	South – South	4.93	7.87	43
Ikeja	South – West	6.75	3.20	40
Ilorin	North – Central	8.26	4.30	308
Onitsha	South – East	6.16	6.78	55
Sokoto	North – West	1255	5.12	351

RUNEOLE, a novel tool for creating weather data that can generate a set of TMY data straight from erratic hourly records, was introduced by David *et al.* in 2010. A substantial collection of Reunion Island's TMYs was produced using the tool that was built. Üner and leri (2000) produced typical hourly weather data for the 23 provinces they chose to represent Turkey's climatic and demographic parameters. To create a TMY for Ankara, Ecevit *et al.* (2002) substituted daily sunshine duration for daily global solar radiation (GSR). Using data from 19 years of measurements, Bulut (2003) created a TRY for daily global sun radiation on a horizontal surface for Istanbul, Turkey. Typical solar radiation years for Southeastern Anatolia in Turkey were also presented by Bulut [10]. From the daily worldwide sun radiation statistics, Bulut *et al.* (2009) developed typical solar radiation years for six provinces in Turkey's Aegean region. In their study, Pusat *et al.* [41] reported the generation of TMYs for a subset of Turkish locations using the FS statistical method to examine measured weather information such as mean, maximum and minimum daily DBTs, mean and maximum daily wind speeds, mean daily GSR and mean daily RHM. Using the database programming language SQL, Yilmaz and Ekmekci [55] created the TMY and climatic database of Turkey for the energy analysis of buildings. The hourly collected meteorological data over a 23-year period were analyzed using the FS statistical approach (1989–2012). Amega *et al.* [5] produced a TMY dataset for the estimation and study of the annual output of renewable energy in five chosen Togo localities.

Presently, there are scanty reports of TMY weather data being developed for Nigerian sites thus far. Fagbenle [15] created a TRY for Ibadan based on a 10-year meteorological data set from 1979 to 1988, in which the normal months were chosen and concatenated to generate the typical year. Using the FS statistical method, Oko and Ogoloma [35] reported data for the TMY for the Port Harcourt climatic zone based on hourly meteorological data recorded between 1983 and 2002. According to the study, the DBT, RHM and wind speed for the Port Harcourt climatic zone were determined to be 26.7°C, 78.6% and 3.5 m/s, respectively, whereas the GSR was found to be 13.5 MJ/m^2/d. The zone's TMY data has been proved to be sufficiently dependable for engineering purposes. Ohunakin *et al.* [33] used the FS statistical method to analyze a 34-year period (1975–2008) of hourly measured weather data (GSR, DBTs, precipitation, RHM and wind speed) to produce TMYs for five locations spread across the northeast zone of Nigeria. A close-fit agreement was observed between the generated TMY and long-term averages. Oyedepo *et al.*, [36] developed TMY data for Abeokuta (7°7'1" N, 3°22'13"E), in Southwestern Nigeria by the use of a modified Sandia method. The study made use of seven weather parameters obtained through 29 years (1984–2012) for the development of the TMY.

None of the previous works cover the six geopolitical zones of Nigeria. This is the first time that TMYs cover all the six geopolitical zones in Nigeria. Hence, the prime objectives of this present study are to: (i) generate TMY data for six selected locations that cut across the six geopolitical zones in Nigeria using the Sandia method, (ii) analyse the major characteristics of Nigerian weather and to examine climate effects on optimal usage of renewable energy systems. A study of this kind is relevant for designers, architects, planners and contractors for proper selection of energy systems and application of energy-related projects. In addition, it will be very a useful source for building simulations to estimate the annual energy consumptions of buildings.

2 MATERIALS AND METHODS

2.1 Data collection and selection of study locations

In this study, 23-year meteorological data was obtained from Nigeria Meteorological Station (NIMET) Oshodi, Lagos and NASA (GEOS-1) Multiyear Time-series Data Web site (1994–2016) for the six selected locations considered in this study. The selected locations, which are representations of the six geopolitical zones of Nigeria, are presented in Table 1.

The following important climatic factors and locations were used in this study to generate the TMY database[22]:

- Information about the location (such as latitude and longitude)
- Data on temperature (*e.g.* DBT)
- Data on humidity or moisture (*e.g.* wet-bulb temperature (WBT), DPT and RHM)
- Solar radiation data (such as GSR)
- Wind data (such as wind speed and wind direction)

It should be noted that the depth of the weather database will depend on how many years of weather data are available. In general, a proper TMY analysis should take into account as many years as possible [21]. The results will be better and more convincing the longer the duration of records (because shorter periods will exhibit variations from the long-term average). The two most important factors in choosing stations were the data's completeness and the time period it covered. Among the seven weather variables included in the data used for this study are DBT (mean, maximum and minimum), DPT/frost point temperature, RHM, GSR and wind speed[20].

2.2 TMY development procedure using Sandia method

Among the several TMY-generating methods described in the literature, the Sandia National Laboratories method using the FS statistical method was selected for this work. This is as a result of its widespread use and ease of use based on retrospective analysis for research and applications in the modern era. In addition, it is the TMY generation technique that is used the most frequently [25].

According to Pissimanis (1988)[40] and Argiriou *et al.* [6], generation of TMY using the Sandia approach involves appropriate choice of individual months to become the TMMs selected from different years of the data. This is an empirical methodology for TMY generation. This means that if the data spans 15 years, all 15 January months will be analyzed, with the most common month being chosen. For the next 11 months, the same practice is followed. As a result, the neighboring months could be from completely different years, and there could be some gaps between them. Curve-fitting techniques such as local mediation with Gaussian variables and interpolation with cubic spline functions were used to smooth them out for a total of 12 h, 6 h on each side[9].

2.2.1. *Selection of typical months*

In this study, the typical month was chosen using the maximum, minimum and mean daily values of weather characteristics such as DBT and RHM; maximum and mean values of wind speed and total global horizontal radiation. The following steps were taken in the initial selection of typical months:

STEP 1: Arrange the daily mean values for each parameter and calculate the long-term and short-term cumulative distribution functions (CDFs) for each month.

$$FS_{xi}\left(y,m\right) = \frac{1}{N_d}\sum_{j=1}^{N_d} \mid CDF_m\left(x_{i,j}\right) - CDF_{y,m}\left(x_{i,j}\right) \mid \qquad (1)$$

Where $FS_{xi}\left(y,m\right)$ is the FS statistics of the parameter x_i for year y and month m, j is interval number of data andN_d is the total number of data intervals.

STEP 2: Compute the weighted sums (WSs) of FS_{xi} using equation (2) [40]:

$$WS\left(y,m\right) = \frac{1}{N_p}\sum_{i=1}^{N_p} WF_{xi}.FS_{xi}\left(y,m\right). \qquad (2)$$

With a condition that:

$$\sum_{i=1}^{N_p} WF_{xi} = 1 \qquad (3)$$

Table 2. *Weighting Factors of Finkelstein-Scharfer Statistics for Past and Present Research Works*

	Weight (w_j)			
Parameter	**Petrakis**	**Pissimanis**	**Sawaqed**	**This Work**
DBT (minimum)	1/24	1/24	1/22	1/12
DBT (maximum)	1/24	1/24	1/22	1/12
DBT (mean)	1/24	2/24	1/22	1/12
DBT (range)	1/24	—	1/22	—
DPT (minimum)	1/24	1/24	1/22	—
DPT (maximum)	1/24	1/24	1/22	—
Dew point (mean)	1/24	2/24	1/22	1/12
Dew point (range)	1/24	—	1/22	—
Wind velocity (min)	1/24	—	—	—
Wind velocity (max)	1/24	2/24	1/22	—
Wind velocity (mean)	1/24	2/24	1/22	1/12
Wind velocity (range)	1/24	—	1/22	—
RHM	—	—	—	1/12
Solar radiation	12/24	12/24	12/24	6/12

Where $WF_{xi}$is the weighting factor for the FS of the variable x_i and $N_p$is the total number of the parameters. The value of the weighting factors for various weather characteristics tends to fluctuate, and these factors are chosen based on previous knowledge of how the meteorological parameters used in the simulation affected the application. As a result, the weighting factors for each parameter differ from one research study to the next. Table 2 displays the weighting factors that various researchers used.

In general, the weights are chosen without regard to any basic rationale. Arigirou *et al.* (1999) allocated weights to meteorological characteristics based on previous experience with their impact on the desired application. The selection of weights is based on the desired application for which the TMY is generated, according to Hall *et al.* (1978). Daily solar radiation was given a high weighting value in their study because they considered the TMY was developed for solar application [16].

Furthermore, because the solar flux index has such a substantial impact on the other weather indices, it makes sense to give it a higher weight. The weighting factors for this study and other previous works are presented in Table 2. As from other works, the solar radiation is given the highest weighting value among the other variables in this study as shown in Table 2. Moreover, instead of using WBT or DPT as an index, RHM was chosen because the two variables, DBT and RHM, affect the WBT and DPTs, as well as vapor temperature [44].

STEP 3: All individual months are sorted in increasing order of WS values once the weighting factors have been determined. Candidate months were chosen from the 3 months with the lowest WS values, starting with the lowest and working up. The root mean square difference (RMSD) between the hourly radiation in that month and the long-term hourly average radiation (d_i) was determined for each candidate month using equation (4) [17] :

$$RMSD = \left(\frac{1}{n}\sum_{i=1}^{n} d_i^2\right)^{1/2} \qquad (4)$$

Table 3. *The cumulative probability distributions of the short-term and long-term daily **mean temperature** for January over the years 1994–2016*

Day	1994	1995	1996	1997	1998	1999	2000	...	2015	2016	Sorted LTV	CDF
1	19.5	22.81	20.7	20.71	19.55	17.36	24.58		17.17	24	19.85	0.032258
2	20.48	23.2	20.99	20.75	20.22	18.03	25.06		17.26	24.9	20.43	0.064516
3	20.99	23.57	21.34	20.97	20.38	18.35	25.15		17.62	25.04	20.73	0.096774
4	21.41	23.79	21.57	21.12	22.1	18.7	25.35		18.19	25.17	21.10	0.129032
5	22.08	24.09	21.85	22.61	22.17	18.87	25.44		18.29	25.21	21.40	0.16129
6	22.32	24.12	22.06	22.83	22.29	19.39	25.56		18.31	25.4	21.61	0.193548
7	22.5	24.31	22.1	22.93	22.33	19.5	25.72		18.49	25.46	21.84	0.225806
8	22.54	24.4	22.16	23.04	23.14	19.88	25.75		18.57	25.52	22.09	0.258065
9	22.56	24.41	22.2	23.08	23.23	20.06	25.79		19.13	25.9	22.29	0.290323
10	22.67	24.44	22.25	23.13	23.3	20.23	25.8		20.72	26.03	22.48	0.322581
11	22.77	24.6	22.41	23.22	23.33	20.25	25.83		20.97	26.24	22.64	0.354839
12	22.92	24.75	22.71	23.41	23.63	20.42	25.87		21.13	26.31	22.83	0.387097
13	23.05	24.8	22.94	23.49	24.94	20.46	25.92		21.14	26.6	23.03	0.419355
14	23.08	24.91	23.08	23.66	24.97	20.47	25.92		21.16	26.7	23.17	0.451613
15	23.16	25	23.22	24.17	25.22	20.61	25.97		21.24	26.74	23.40	0.483871
16	23.18	25.03	23.25	24.25	25.23	20.8	26.04		21.31	26.85	23.63	0.516129
17	23.34	25.24	23.38	24.3	25.49	20.97	26.05		21.33	26.86	23.85	0.548387
18	23.62	25.97	23.39	24.34	25.82	20.99	26.16		21.36	26.89	24.00	0.580645
19	23.73	26.05	23.61	24.7	26.02	21.18	26.69		21.41	27.02	24.15	0.612903
20	23.8	26.06	23.67	24.85	26.16	21.2	26.81		21.44	27.07	24.30	0.645161
21	23.98	26.13	23.79	24.88	26.19	21.24	26.93		21.69	27.15	24.48	0.677419
22	24.25	26.39	23.86	25.16	26.25	21.29	26.94		21.78	27.21	24.67	0.709677
23	24.56	27.1	23.89	25.27	26.55	21.78	26.96		22.26	27.23	24.97	0.741935
24	25.11	27.18	24.13	25.64	26.6	21.81	27.03		22.28	27.42	25.23	0.774193
25	25.14	27.29	24.3	25.97	26.79	21.83	27.19		23.51	28.52	25.52	0.806451
26	25.18	27.5	24.53	26.3	27.01	21.87	27.27		24.62	28.78	25.80	0.838709
27	25.64	27.68	24.63	26.54	27.08	21.93	27.37		26.47	29.35	26.04	0.870967
28	25.99	27.99	24.96	26.61	27.24	21.96	27.58		27.62	29.56	26.30	0.903225
29	26.22	28	25.15	26.98	27.63	22.19	27.71		27.92	29.64	26.59	0.935484
30	26.35	28.26	25.16	27.03	27.68	23.45	27.73		28.04	29.85	26.90	0.967742
31	26.42	28.86	25.9	27.4	27.92	23.74	28.3		28.86	29.96	27.30	1

The number of data pairings is denoted by n. The candidate month with the fewest RMSD was chosen as a member of that station's TMY.

The average month was determined based on the seven characteristics outlined earlier under the Sandia method of TMY development. The method's procedural steps are explained in the following section, 1 month at a time, over the course of a year:

2.2.2. *Statistical analysis and selection of TMM*

STEP 1: The daily (short-term) values for each meteorological parameter under consideration are first sorted. Table A1, for example, presents the sorted and unsorted mean temperature for Sokoto in January 1994. The average values generated when these values are averaged across the years for each day in a given month are referred to as long-term values [18].

STEP 2: Calculate the long-term daily mean values for each parameter for the 23-year period studied, and create CDFs for both the short-term and long-term daily mean values for each parameter. The CDF for a given parameter is calculated as follows for a given month. If n is the number of days in a month, we have n values in the month for the provided parameter. As a result, the likelihood that the parameter will adopt any particular daily value is $1/n$. The data must first be arranged in ascending order before the CDF can be calculated. The CDF values are then calculated using the following formula, using the rank index of the sorted data as the rank index [13]:

$$CDF_J = \frac{1}{n}j, \qquad j = 1, 2, ..., n \tag{5}$$

STEP 3: Five candidate months are chosen from the corresponding months of the years considered in the construction of the TMY for each month of the year. These are the months with the closest short-term to long-term CDFs across all parameters (elements). The absolute difference (δ) between the short-term and long-term CDFs determines how close they are. The absolute differences of the daily mean temperature index for the year 1994, for example, are shown in Table 3.

The step—by—step procedure for the selection of the five candidate months is presented as follows:

(a) Calculate the FS statistic for index j, j = 1,2,3,..., n (number of indices studied), for the month under consideration, using equation (6) (Finkelstein and Schafer, 1971):

$$FS_j = \frac{1}{n}\sum_{i=1}^{n}\delta_i \qquad i = 1, 2, ..., no.of\ days\ in\ month \tag{6}$$

Table 4. *WSs sorted in ascending order and their corresponding years for two sample months*

S/N	Year No	Year **January**	WS	Year No	Year **August**	WS
1	14	2007	0.853733287	9	2002	1.612106124
2	19	2012	0.895816036	12	2005	1.817208509
3	8	2001	0.965300374	6	1999	1.871087658
4	4	1997	0.983969612	11	2004	1.951638382
5	13	2006	1.090652875	7	2000	1.968828658

Table 5. *The corresponding years for the sorted WSs for all months*

1	**2**	**3**	**4**	**5**	**6**	**7** ***Candidate Months***	**8**	**9**	**10**	**11**	**12**
14	12	13	17	17	8	23	9	6	12	6	13
19	15	12	11	15	13	13	12	13	14	16	1
8	4	11	19	19	7	20	6	10	8	22	18
4	13	17	16	16	15	16	11	14	11	17	4
13	9	19	21	18	4	18	7	19	20	15	16

Where,

δ_i= For day i in the month, the difference between the short-term and long-term CDFs is the absolute difference.

n = number of days in the month.

j = is the parameter (index) considered. For mean temperature, j = 1; for max temperature, j = 2; for solar flux, j = 7

(b) Each index is given a weight, and the WS of the FSj statistics for the month is computed using the formula:

$$WS = \sum_{j=1}^{n} w_j FS_j \tag{7}$$

where,

n = no. of indices (parameters/elements) considered.

W_j = weight for index j

FS_j = FS statistic for index j.

The weights assigned in this work are as given in Table 2 along with that of other workers.

(c) For each month of the year, five candidate months are chosen from five distinct years. It's the months with the smallest WS. This is accomplished as follows [19]:

(i) Sort the WSs in ascending order
(ii) For any particular month select the first 5 year numbers.

Table 4 shows the 2-months sorting (January and August). The five possible months for January are the 14th, 19th, 8th, 4th and 13th years (corresponding to 2007, 2012, 2001, 1994 and 2006). These candidate months are then subjected to a second round of selection, with one of them being chosen to be included in the TMY year, as explained later. Similarly, the candidate years for August are 2002, 2005, 1999, 2004 and 2000. Table 5 shows the summary of the candidate months for the year. The year numbers shown later represent the most favorable five candidate years selected for each month.

STEP 4—The five potential months were ranked according to their proximity to the long-term mean and median for two indices: mean ambient temperature and global radiation. This was accomplished as follows [12]:

a. The long-term mean and median for the month in question, as well as the short-term mean and median for the five candidate months, are calculated. This is done by sorting the data in ascending order first. The medians are then calculated, as shown in Table A2 for each of the 5 years' Januarys.
b. As indicated, the long-term median is also discovered. Similarly, when it comes to the solar flux parameter (Table A3).
c. Based on the data in Tables A2 and A3, four differences are estimated for each of the five candidate months. For both indexes, these are the absolute disparities between the short-term and long-term mean and median (temperature and solar flux).
d. Assign the highest difference from the four differences found to each month, and then rank the 5 months in increasing order of their allocated differences.

Table A4 for January shows the previous two substeps (b and c). Table A5 summarizes the selected months in order of their four differences as previously mentioned for the other months.

STEP 5—To evaluate the persistence of mean DBT and daily global horizontal radiation on the five candidate months, determine the frequency and run length above and below established percentiles. For the first month of the five candidate months for mean daily DBT, Table A6 displays the frequency (number of runs) and run(s) length(s) above the 67th percentile (consecutive warm days) and below the 33rd percentile (consecutive chilly days). For January, the first month of the selected 5 months, the frequency (number of runs) and run(s) length(s) below the 33rd percentile (consecutive low-radiation days) are determined as shown in Table A6. Table A7 displays the number of runs (frequency of runs) and their lengths for the selected 5 months in January and February.

STEP 6—Based on the aforementioned persistence evaluation, a single month to be included in the TMY year was chosen from among the five candidate months rated as previously indicated in **STEP 5**, using an elimination mechanism in the following order:

Number of Runs Criterion:

a. If none of the 5 months have any runs, the first month in the ranking list is chosen.
b. If the number of runs in each of the 5 months is the same, examine the length of the runs and proceed with the exclusion as follows [26]:
c.
   i. If the run lengths of the months are unequal, the one with the longest run is excluded.
   ii. If their run lengths are equal, the last one on the list gets eliminated.

c. If the number of runs in each month is not equal, the month with the most runs is eliminated.

- ***Runs Length Criterion:***

a. If the remaining months have different run lengths, the one with the longest run is eliminated.
b. If the remaining months' runs are all the same length, count the runs and proceed as follows:
   i. If the total number of runs for the next months is equal, the last one in the list is eliminated.
   ii. If the number of runs for the remaining months are not equal, the month with the most runs is eliminated.

- ***Zero-Run Criterion:*** Examine the next months to see how many runs there are. Leave out the one with zero runs (if any).

The foregoing exclusion criteria will result in a 3-month maximum or 2-month minimum removal, leaving 2 or 3 months remaining, accordingly. Table A8 with index (0) shows the months that were deleted using the aforementioned technique. As a result, 2 months were dropped in January. The month to be included in the TMY year is then picked as the first month in the list from the remaining 2 or 3 months (with index (1) in Table A8). In Table A8, the TMM is indicated and highlighted. Table A9 is a summary of the months that make up the TMY.

STEP 7—Finally, the 12 TMMs are then concatenated to form the TMY.

2.3 Estimation of percentage error

Mean percentage error (MPE) was used in this study to calculate the percentage error between the long-term and TMY values of each respective index of the chosen meteorological parameters. MPE was chosen because it is frequently favored for the long-term performance of the relations under examination [43]. Cross-sectional forecast evaluation frequently uses MPE. It has useful statistical characteristics in that it uses all observations and has the least variation between samples. As stated by Ohunakin *et al.* [33]:

$$MPE = \frac{1}{n}\left[\sum\left(\frac{f_{LT} - f_{TMY}}{f_{LT}} \times 100\%\right)\right] \tag{8}$$

where f_{LT} and f_{TMY} are the long-term and TMY values of each of the respective indices of the selected weather parameters, *n* is the number of months. Low values of MPE are thus desirable.

3 RESULTS AND DISCUSSION

The TMYs of the stations are created by using the preceding approach and the data at the six selected locations. The FS statistics of each index are compared and calculated for each calendar month. Estimates were made using the weighting variables listed in Table 1 to account for the influence of various meteorological conditions in the FS statistics and, as a result, in the selection of sample months. The FS statistics were calculated, and the result was a weighted total.

3.1 Monthly variation of GSR

Figure 1 depicts the monthly GSR in MJ/m^2/day estimated from measured data for the six selected locations (Sokoto, Ikeja, Onitsha, Abuja, Akwa-Ibom and Ilorin), which represent Nigeria's six geopolitical zones. The long-term mean values (averaged through 23 years) and those for the TMY are also displayed. The TMY values in the graph were obtained by averaging the daily data for the TMM in question, resulting in monthly averages. The TMY values substantially correlate with the long-term values for all of the selected locations. In terms of the TMY in general, it is observed that the GSR data for Sokoto shows monthly averages between 19 and 26 MJ/m$^{2/}$day, with the lowest values in January, August and December and the highest values in April. The months with the highest radiations, according to Figure 1, are March through June, with an average monthly global radiation of roughly 25.2 MJ/m^2/day. In addition, the monthly global radiation is maintained at 20–21.5 MJ/m^2/day between September and November. Maximum solar radiation values are recorded in Ikeja between the months of December and March, with peak levels in both February and March (approximately 19.8 MJ/m^2/day), whereas there is a relatively long period of low solar radiation values from June to September (around 14.5 MJ/m^2/day).

The climate of Onitsha is characterized by two distinct seasons; the low-radiation season spanning from July to September and the high-radiation season covering December and March. The crest value of incident radiation is recorded in the second month of the year (~20.1 MJ/m^2/day), whereas the lowest radiation values are taken in August (13.7 MJ/m^2/day). The graph for Abuja location shows that two distinct seasons characterize the GSR in the

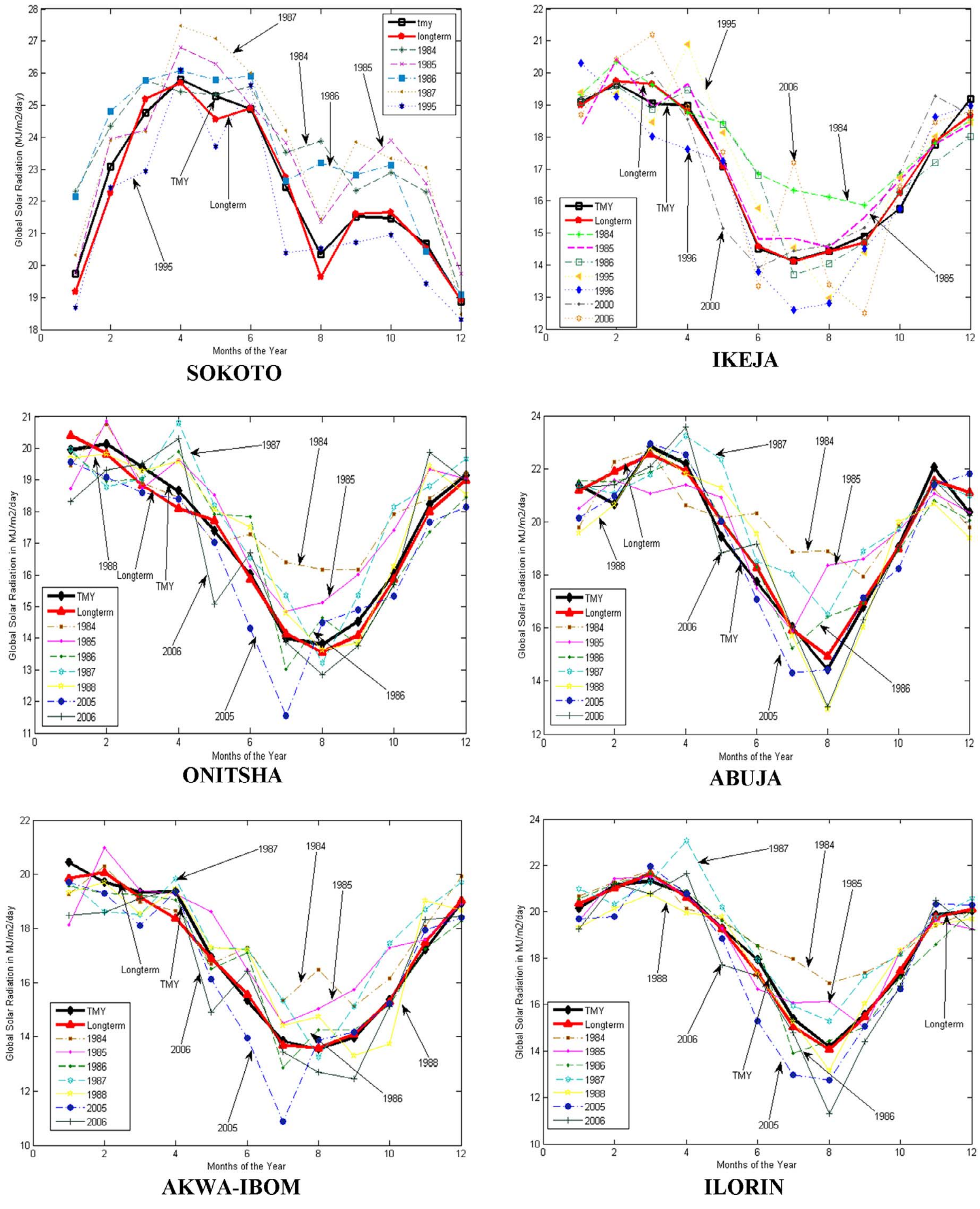

Figure 1. *Monthly variation of GSR for the six selected locations for the whole period of 23 years, for the selected TMY and long-term monthly average.*

location. First is a season having high radiation values spanning through 6 months (November to April) and then a season of low solar radiation values also covering 6 months of the year (May to October). Peak values of radiant energy are detected in March (23.6 MJ/m^2/day), whereas the lowest values are taken in August (<15 MJ/m^2/day). The peak values for the global radiation for Akwa-Ibom are observed to be ∼20.1 MJ/m^2/day occurring in February, whereas the lowest radiation values are recorded in August (13.8 MJ/m^2/day). For Ilorin, the graph depicts the highest global radiation values occurring in March (∼21.6 MJ/m^2/day), whereas the lowest values are shown to be ∼14 MJ/m^2/day in August.

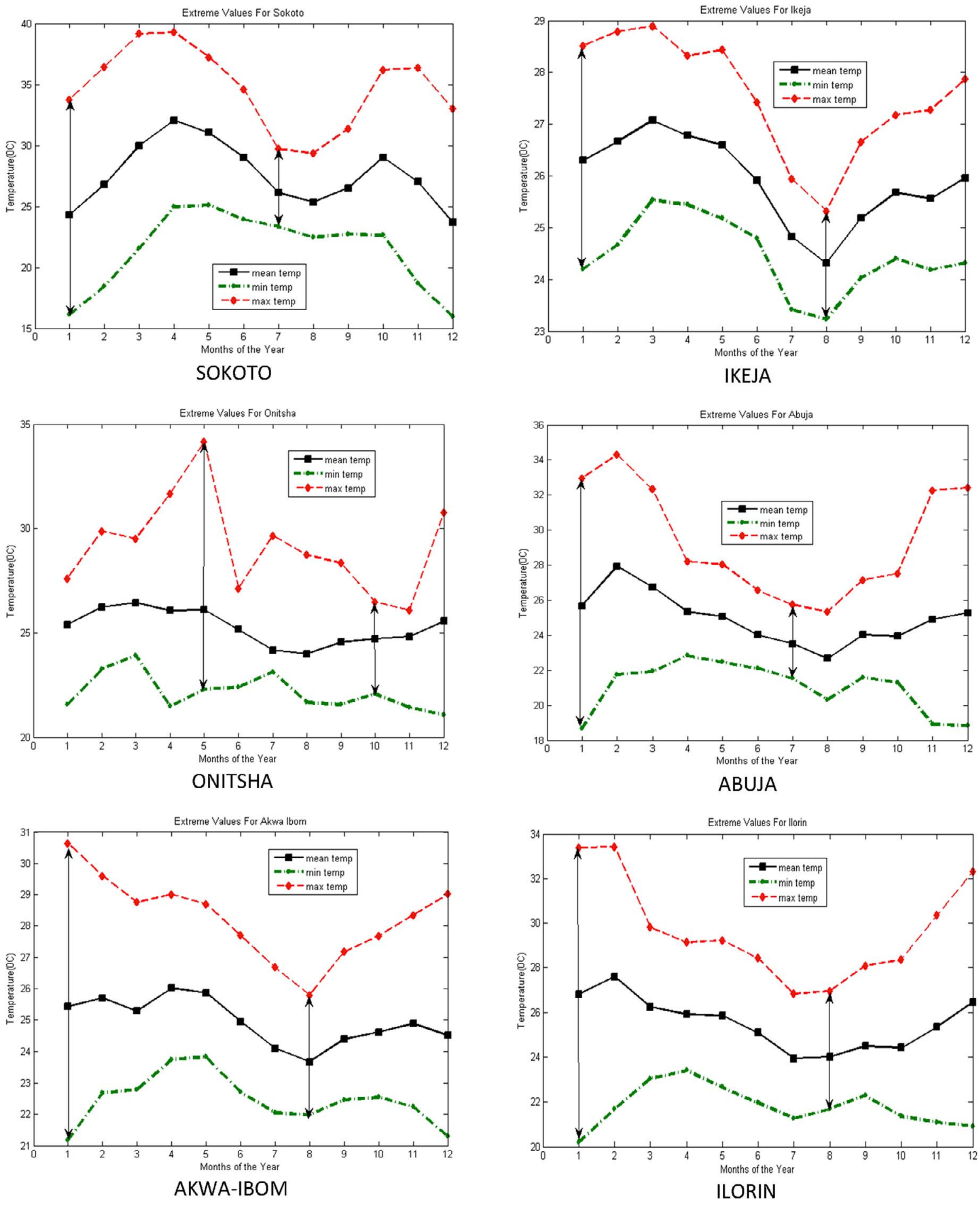

Figure 2. *Monthly variation of DBT (min, max and mean) for the whole period of 23 years, for the six selected locations*

This study shows that the values of GSR rise from winter to summer in all the regions taken into account. Furthermore, the amount of GSR increases from the south (Akwa-Ibom) to the north (Sokoto). This was anticipated because the radiation should increase as one moves to the equatorial line. This is in agreement with the study carried out by Sunday [50]. Furthermore, this study's findings indicate that Sokoto has a higher availability of GSR than the other locations examined. In addition, solar energy devices will function successfully throughout the year in Sokoto. The analysis carried out by Sunday [50] showed that with the national average global solar energy of 5.5 kWh/m^2/day and average solar radiation time of 6 h/day are favorable conditions

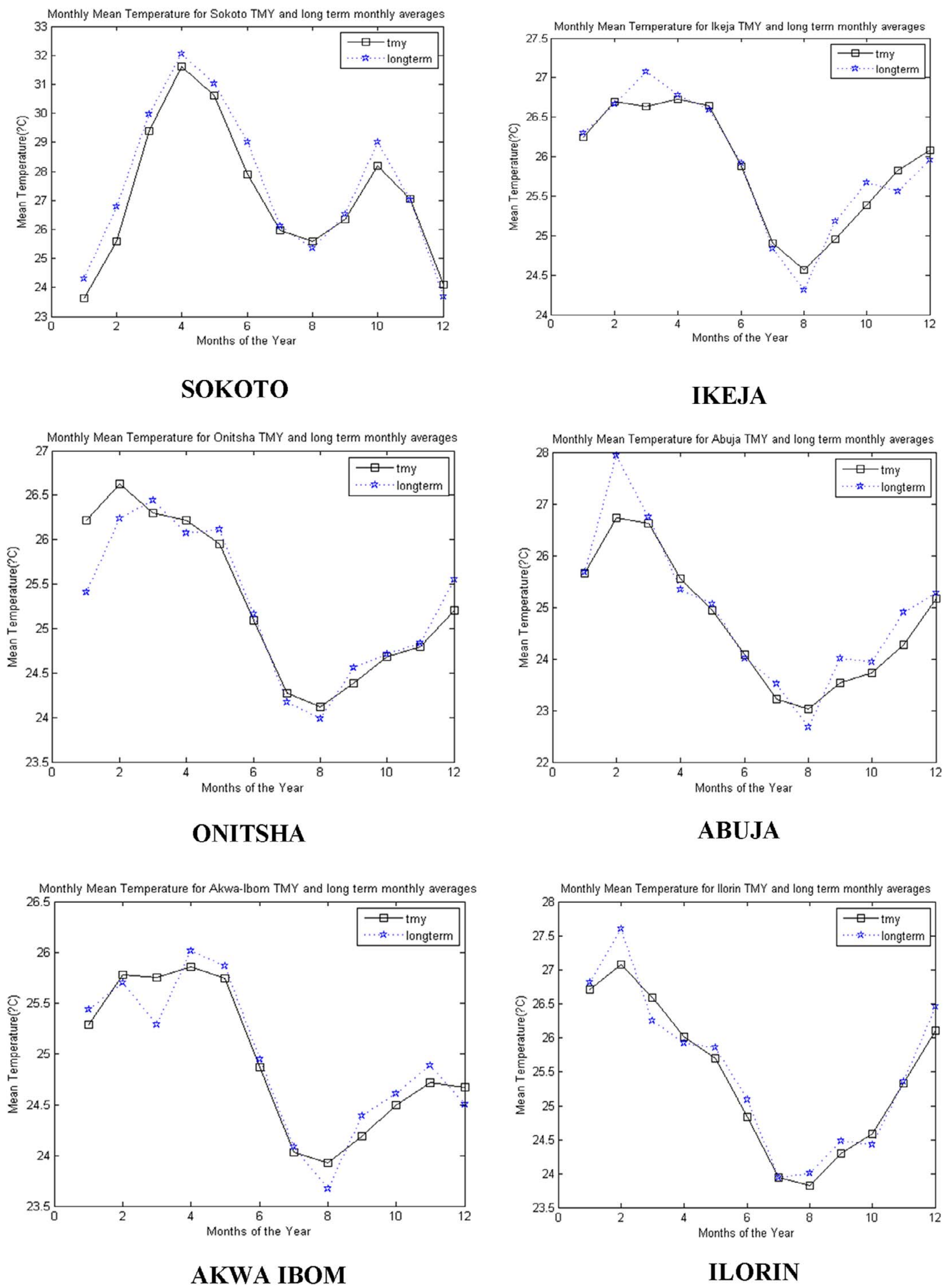

Figure 3. *The monthly mean TMY and the average long-term values of the mean temperature for the selected locations*

for PV power generation in Nigeria. In view of this, considering the GSR in the selected locations, with PV power conversion technology of solar energy into power and the economies of the power generated, the generation of power from solar energy in the selected locations is viable, especially in the North. The annual global solar from this study reveals that solar radiation can be efficiently used to compensate for energy deficit in Nigeria.

3.2 Monthly variation of DBT

Figure 2 shows the monthly variation of DBT (minimum, maximum, mean) for the selected six locations. It is evident from

Table 6. *Annual Cooling Degrees – Day at Different Base Temperature*

Location	Base Temperature (°C)						
	22	24	25	26	28	29	30
Abuja	1834.0	1260.9	1028	827.3	508	384.7	283.5
Ikeja	1785.6	1118.5	833.4	599.6	277.8	178.9	108.5
Ilorin	1671.6	1106.1	881.6	693.2	404.3	296.9	210.5
Sokoto	2429.0	1856.9	1596.1	1356.4	942	767.5	615.2
Onitsha	1881.5	1234.5	970.3	748.6	409.6	286.3	190.1
Akwa-Ibom	1661.2	983.4	716.4	507.5	227.5	140.1	78.5

Figure 2 that for Sokoto, the DBT varies from a low value of 16°C to a high temperature value of ~39°C. It is also observed that large temperature variation exists from October to May in every year, with March having the largest variations of ~18°C. Conversely, the lowest variation is observed to be around the July—August period of the year with average temperature variation of 5°C. Figure 2 describes the extreme temperature variations for Ikeja. The maximum and minimum temperature values are identified to be 28.9°C in March and 23.2°C in August, respectively. The temperature variations for the year are relatively constant and low. However, maximum temperature variations are recorded in January where these variations exceed 4.3°C, whereas the minimum values in variations are experienced in August (not >2.1°C). The graph for Onitsha shows that the temperature of the location is generally low, with maximum possible temperatures not >26.2°C. However, variations in temperature exist in this location with the largest variation occurring in August (~10.2°C) and the smallest temperature variation recorded in January (~5.2°C). Furthermore, the lowest temperature values are detected in August (~13.7°C). Extreme temperature values are observed for Abuja location. The graph shows that strong variations in temperature exist, covering ~5 months. The largest temperature variations are recorded in January with values of ~14.2°C, whereas the smallest variations in temperatures are detected in July (~4.1°C). The maximum temperatures measured are from February (~34.2°C), whereas the minimum temperatures occur between December and January (18.8°C). The graph for Akwa-Ibom also shows the possible extreme temperature values. It can be deduced on the graph that variations in temperature values exist through the year. The largest temperature variations are detected in January, where these variations exceed 9.5°C, whereas the smallest variations of <3.9°C are recorded in August. The maximum temperature values occur in January (30.7°C), whereas the minimum temperature values measured occur also in January (~21.2°C). For Ilorin, it is observed that high temperature variations exist. The largest temperature variations occur in January (~13.2°C), whereas the smallest variations are detected in August (~5.3°C). The highest temperatures are recorded in January (~33.7°C) and the lowest temperature values are detected also in January (~20.2°C).

In Fig. 3, the mean temperature curves of the chosen areas for the TMY and long-term values are shown. The mean temperature charts show similar patterns and a strong fit between the TMY and long-term average for each site. March, which is a month of the region's dry season, saw the curves' peak values. This is consistent with the findings of Sunday [50] and Ohunakin [33].

Studies have revealed that the weather significantly affects the amount of energy used for heating and cooling [28]. Analyzing the effects of climate change on the energy use for heating and cooling buildings is therefore quite practical [46]. This is due to the fact that the heating and cooling degree days indices can quickly and accurately reveal how the climate affects the amount of energy used for heating and cooling buildings [29]. Awolola and Olorunmaiye [8] calculated cooling degree days for the chosen Nigerian cities using base temperatures (hourly DBTs) between 22 and 30°C (Table 6). Although 30°C is the ambient temperature that should not be exceeded if the body is to lose metabolic heat comfortably, the lowest base temperature used in the study (22°C) was just a little bit lower than 24°C, which is the indoor design condition for cooling load calculations for an air conditioning system. The analysis revealed that for Abuja, Akwa-Ibom (similar to Calabar), Onitsha (similar to Enugu), Ikeja and Ilorin, March had the maximum monthly cooling degree days. In May, Sokoto experiences the most cooling days. This is due to the fact that these locations record greater ambient temperatures during the aforementioned months, which mark the changeover from the dry to the wet seasons. For the comfort of people, these temperatures must be lowered, which air conditioning can provide. This suggests that in the month of March, for the five locations that experience the most monthly cooling degree days in March, and in the month of May for Sokoto, the most energy is needed for cooling systems like cold rooms and air conditioning systems.

Figure 2 showed that most places in Nigeria have high ambient temperatures, necessitating the need for space cooling throughout the year, but notably during the months of March, April and May, which have the most cooling degree days. The locations with lesser cooling degree days are those in the coastal areas, for example Ikeja and Akwa-Ibom. Tejero-González *et al.* [51] contend that outdoor weather has an impact on the operation of the air conditioning system in addition to the demand for it. The coefficients of performance (COP) of traditional compression cooling systems depend on both comfort set points and ambient temperatures. According to a 2014 study by Yau and Pean [54], COP can decrease by 2% for every 1°C increase in ambient temperature. As a result, this emphasizes how future climate change scenarios will affect the effectiveness and applicability of HVAC equipment.

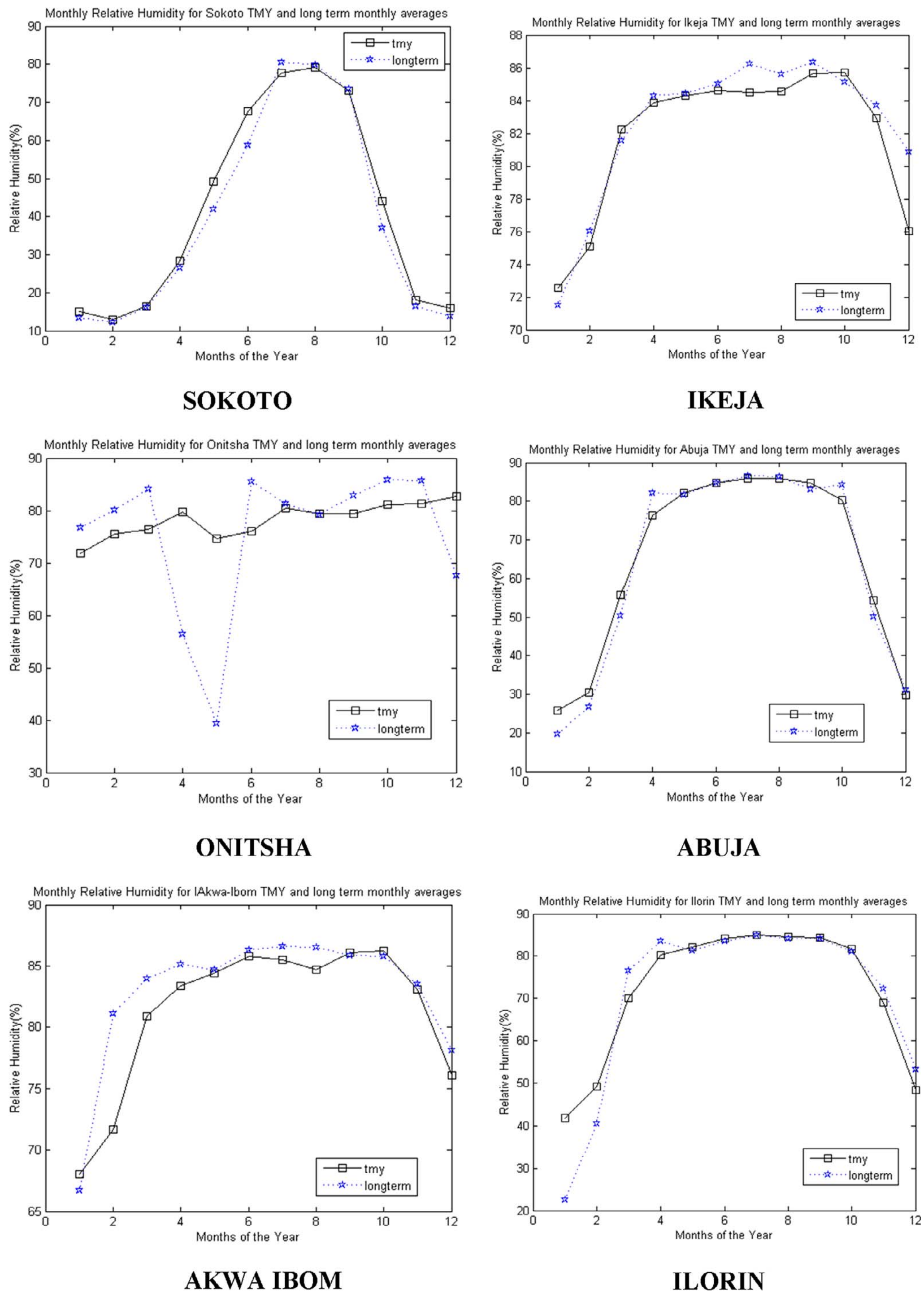

Figure 4. *The monthly mean TMY and the average long-term values of the RHM for the selected locations*

3.3 The monthly mean TMY and average long-term values of RHM, wind speed and DPT

The TMY and long-term curves for the RHM, wind speed and DPT, respectively, are shown in Figures 4–6. For Sokoto, the graph shows that the wind speed is generally constant and relatively high throughout the year. Maximum values of wind speed with magnitudes of ∼4 and 3.7 m/s are experienced in February and December, respectively. The variations in the DPT and the RHM are in concordance. This is so because both parameters are closely related. Maximum values of RHM are observed between July and September with the highest value of 80% in July. The peak values for DPT occur from June to September with highest value

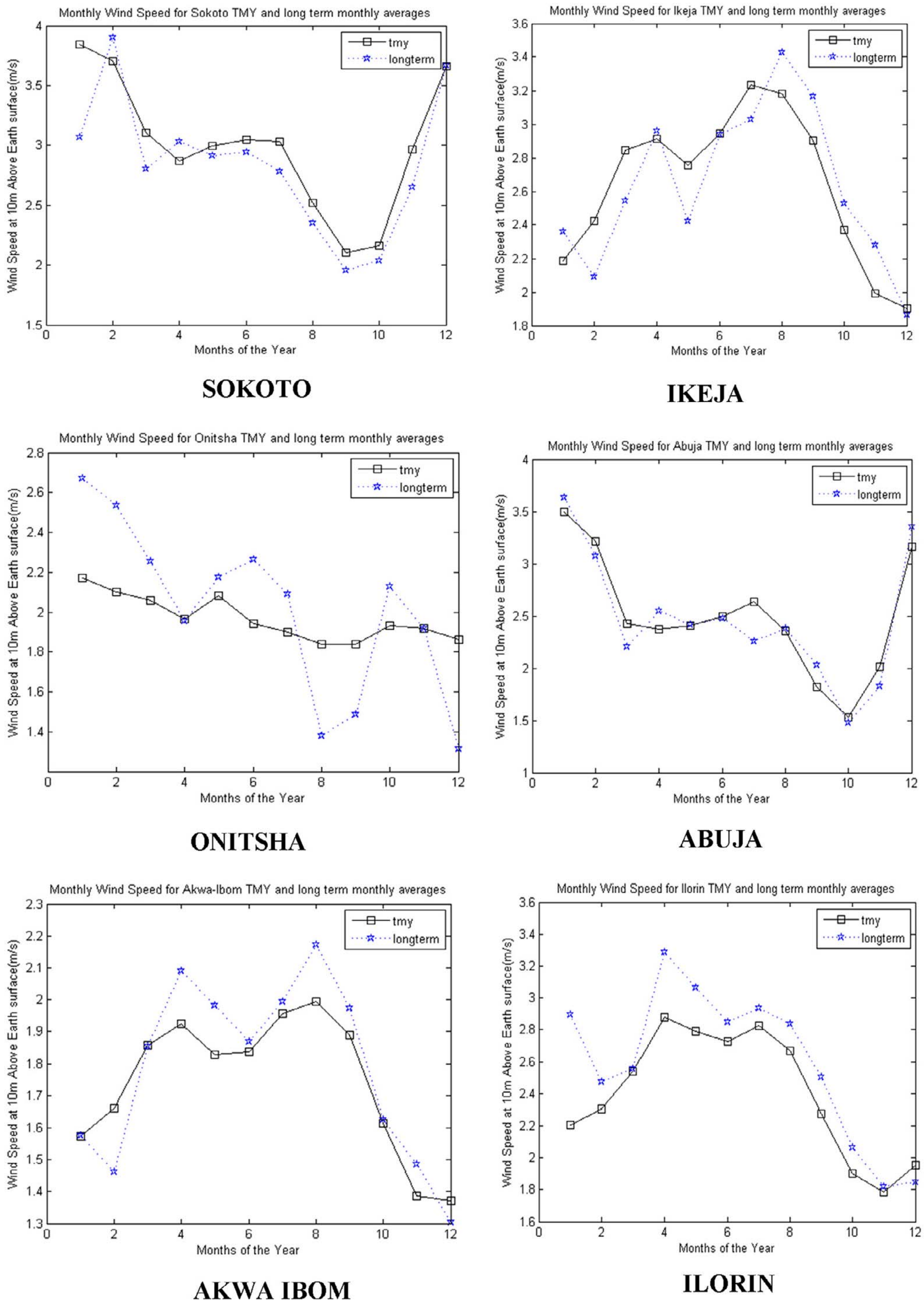

Figure 5. *The monthly mean TMY and the average long-term values of the wind speed for the selected locations*

of ∼22°C in July. On the other hand, the root values for both RHM and DPT occur in February (∼13%) and January (∼−4°C), respectively. For Ikeja, it is observed that RHM is high and fairly constant throughout the whole year with the highest occurrence in July (∼87%) and the lowest value in January (∼72%). The location is also characterized by low wind speed with average values of ∼2.5 m/s. The highest wind speed is experienced in August reaching tops of ∼3.4 m/s, whereas December is the month having lowest wind speeds of ∼1.9 m/s. And then, similar to the RHM, the DPT of the location is relatively constant throughout the whole year with the highest values occurring in March and April (24°C), whereas the lowest DPT values occur in August (21°C). For Onitsha, it is observed that the RHM for the location is fairly constant and high for 8 months of the year and then dips down

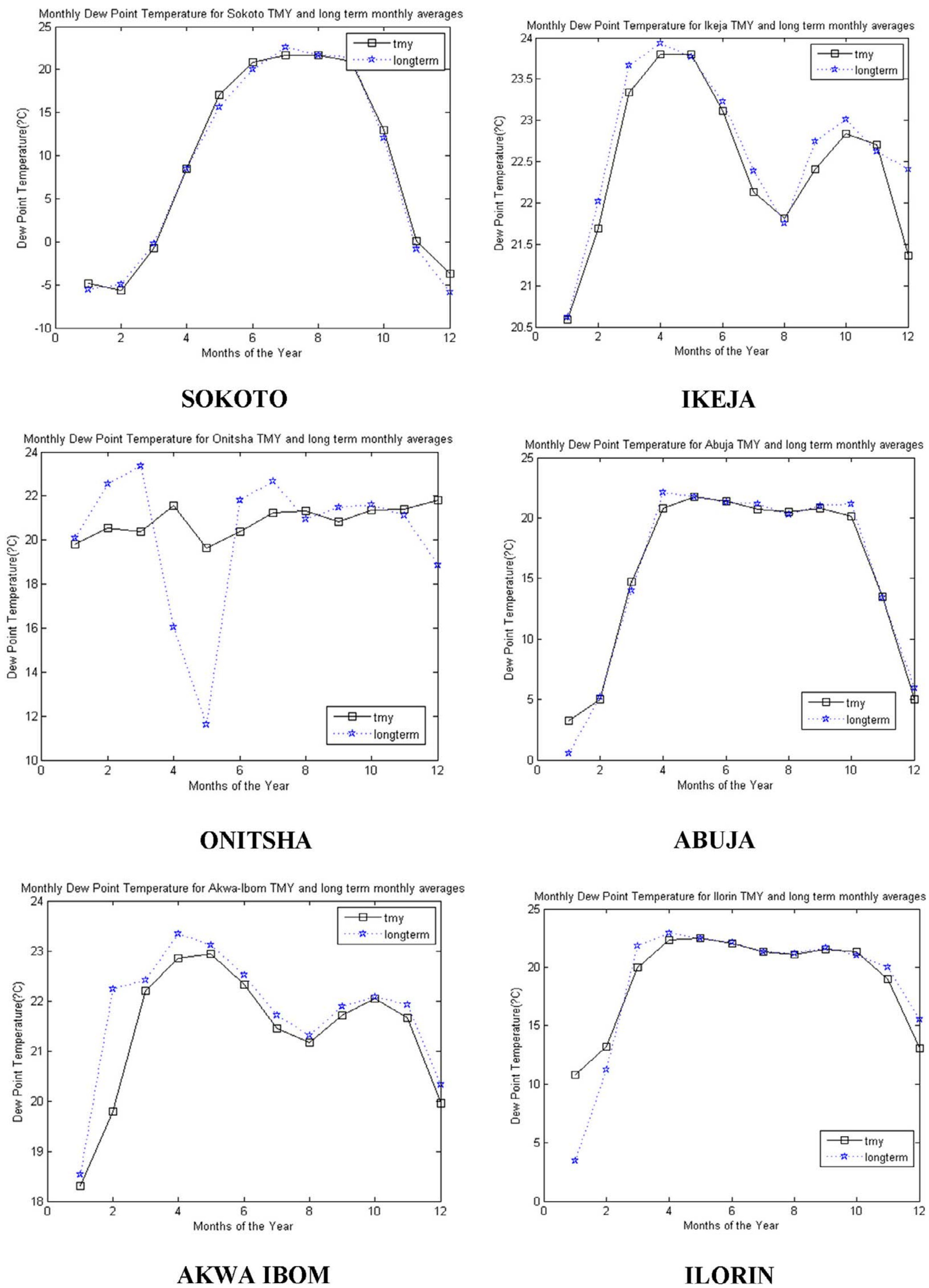

Figure 6. *The monthly mean TMY and the average long-term values of the DPT for the selected locations*

in value between April and May. The highest percentage of RHM is recorded in June (89%), whereas the root value in percentage is detected in May. The wind speed for the location is moderately constant throughout the year with an average value of ∼3 m/s. The DPT for the location is also relatively constant but dips down between the months of April and May. The location at Abuja has extreme values for RHM, DPT and wind speed. The graph shows that the RHM is considerably constant for ∼8 months with topmost percentage values recorded in July (∼88%) before dropping down to values as low as 20%. The DPT values for the location behave in like manner to the RHM, being constant at ∼21°C for the 8 months before dropping to as low as 0.1°C in January. The

Table 7. *Comparison of MPE (%) of the long-term average values of parameters with TMY for the respective locations*

Location	MPE (%)				
	Mean Temperature	GSR	Wind Speed	RHM	DPT
Abuja	-0.075	0.06	0.131	0.119	0.038
Akwa-Ibom	-0.0076	-0.043	−3.67	-0.152	0.257
Ikeja	-0.011	0.037	−0.0029	-0.036	1.480
Ilorin	-0.025	-0.034	−0.7 47	0.177	0.221
Onitsha	0.0284	0.074	−0.433	0.183	0.190
Sokoto	-0.147	0.068	0.495	0.430	0.156

location is characterized by wind speeds of desirable levels, being constant at values of ∼2.5 m/s for 9 months between March and November, then increases a little to values of ∼4 m/s between December and February.

The graph for Akwa-Ibom shows that the RHM is fairly constant and high for ∼11 months in the year between February and December (peak value of 88% in July), with just a dip in percentage value to ∼67% in January. In addition, the DPT for Akwa-Ibom remains constant for ∼11 months and dips a little to 19°C in January. Finally, the wind speed values at this location are at low values throughout the year. Top wind speeds, just ∼2.1 m/s, are detected in August, whereas the lowest wind speed recordings are taken in February and December (∼0.5 m/s). For Ilorin, the RHM remains fairly constant for 9 months in a year and then dip into low values within the remaining 3 months. The peak percentage values for RHM are recorded in July (having values of ∼86%), whereas the root percentage values are measured in January (24%). The DPT for the location also behaves in like manner to the RHM, being constant for 9 months of the year at values ∼22°C. The wind speed for Ilorin seems to be constant throughout the year at speeds of ∼3 m/s.

In all of the places taken into consideration, a consistent pattern can be seen in the RHM and DPT. For the long-term averages, Onitsha and Akwa-Ibom show slightly wider variance, which is particularly noticeable during the rainy season; the curves are also observed to peak for RHM and dew point between July and September in all the sites. Regarding the wind speed curves, there is an uneven trend for both the TMY and long-term mean values throughout the zones. Although there exists variation in the wind speed across the selected sites, there exists wind energy potential for different applications (electricity generation, water pumping, *etc*) in the selected sites. In this regard, wind turbine performance specifications have been carried out for selected locations in Nigeria. Adaramola *et al*. [2] and Oyedepo *et al*. (2012) [37] evaluated the wind energy potential in selected locations in Nigeria and assessed the performance of seven selected small- to medium-size commercial wind turbines for generation of electricity. The selected wind turbine models include P15–50, P19–100, P50–500 and P62–1000 models (Polaris America LLC, Lakewood, NJ, USA); WES30 model (Wind Energy Solutions BV, The Netherlands); WWD-1-60 model (Winwind, Espoo, Finland) and BONUS 1000–54 (Siemens AG, Erlangen, Germany). The power rate of the selected wind turbine models ranged from 50 to 1000 kW. The studies revealed that minimum annual energy output of ∼18.83 MWh/year could be produced at Onitsha using the P19–100 model, whereas maximum annual energy output of 461.32 MWh/year could be produced with the WWD-1-60 model. The minimum and maximum annual energy outputs at Abuja and Ilorin were ∼5 and 78 kWh/year and 15 and 130 kWh/year using P15–50 and P50–500 models, respectively. The P50–500 model has the highest value among the models considered for Ilorin, Abuja and other locations in the northeast of Nigeria. This is because its hub height is highest among the models considered in the study. In another study by Paul *et al.* (2011) [38], it was shown that based on electricity usage of 126 kWh per capital per year in Nigeria as of 2008, the annual energy output from the S-343 wind turbine model can serve the electricity needs of ∼10 people in Warri and Uyo (Southern Nigeria), whereas annual energy produced by the WES30 wind turbine model can serve ∼1750 people in Ogoja (Southern Nigeria).

To quantify the degree to which the TMY deviates from long-term averaged values, the MPE of the TMY from the long-term average was estimated in addition to the graphical comparison. The MPE results for all sites and for the primary meteorological parameters are shown in Table 7. When compared with the long-term average value, the TMY value was underestimated and overestimated, respectively, according to the positive and negative values of MPE. Table 7 shows that the monthly averaged mean DBT, GSR and RHM fluctuations are all within 1% of the long-term averaged values for all the sites. The greatest values of the MPEs for TMY and long-term averages were found to be 3.67% (Akwa-Ibom) and 1.48% (Ikeja), respectively, for wind speed and DPT. From the aforementioned, it can be concluded that the long-term values for the weather characteristics taken into consideration in this study and the TMY have a good fit. This outcome is consistent with the study of Yang *et al*. [53], who reported that the TMY's monthly load and energy use profiles did, in fact, follow the long-term means quite well.

4 CONCLUSIONS

In this study, the Sandia technique was used to generate the TMY database for optimal usage of energy systems at six selected locations in Nigeria during a 23-year period using climate data from six geopolitical zones. Graphical approaches are effective for assessing and interpreting climate data, according to the findings of the study. The resulting TMY data's deviations from long-term mean data was statistically evaluated using MPE and found to be modest, indicating that the TMYs were legitimate. Mean temperature, GSR, wind speed, RHM and DPT show low variation in TMY values to the long-term values (less than 5%) for all the selected locations. Seasonal fluctuation, on the other hand, shows that there are two distinct seasons in a year: the wet/rainy season and the dry/harmattan season. Low solar radiation values, high humidity, and small variations in day and night temperatures characterize the former season, whereas low humidity, high solar radiation values (due to reduced cloud cover and increased clearness index) and strong day-to-night temperature variations characterize the latter season. Weather characteristics of the North region allow for the use of solar-thermal systems, whereas the South region, although not suitable for solar systems, agrees to the use of evaporative cooling to reduce the thermal load of buildings. Moreover, the study shows that the ambient temperature of most locations in Nigeria is high; therefore, it is required that space cooling is expected throughout the year most especially in March, April and May with the highest cooling degree days. The locations with lower cooling degree days are those in the coastal areas. Four locations (Sokoto, Abuja, Ikeja and Ilorin) have wind energy potential for electricity generation and water pumping. Building components and energy systems are expected to be properly planned to take full advantage of the behavior and interplay of weather conditions to achieve energy-efficient design and operations. As a result, the evolution of a normal meteorological year is critical for energy system optimization. This study is crucial because it serves as a guide for describing the normal meteorological features of the chosen Nigerian areas. This study provides a reliable database for practitioners who are engaged in design, installation and maintenance of energy systems in the Nigeria climatic zone.

SUPPLEMENTARY DATA

Supplementary material is available at *International Journal of Low-Carbon Technologies* online.

AUTHOR CONTRIBUTIONS

KO (Study conception, graphic design and reviewed the manuscript), SOO (Study conception, design, interpretation of data and review), DOJ (Data acquisition and analysis), LOR (Review the manuscript), BOP (Reviewed the manuscript and approved the final version to be published), AKA (Reviewed the manuscript), UM (Reviewed the manuscript), OMA (Data acquisition & interpretation and preparation of the manuscript), AIM (Reviewed the manuscript and approved the final version to be published) and BS (Reviewed and edited the manuscript, approved the final version to be published).

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APPENDIX A

Table A1. *Short-term daily average temperature values for January 1994 (Sokoto)*

Day	Unsorted	Sorted	Corresponding Day
1	24.25	19.5	17
2	23.34	20.48	18
3	23.62	20.99	16
4	22.32	21.41	19
5	22.5	22.08	6
6	22.08	22.32	4
7	23.08	22.5	5
8	23.73	22.54	20
9	25.11	22.56	23
10	25.64	22.67	26
11	26.22	22.77	21
12	25.99	22.92	24
13	26.42	23.05	15
14	26.35	23.08	7
15	23.05	23.16	22
16	20.99	23.18	25
17	19.5	23.34	2
18	20.48	23.62	3
19	21.41	23.73	8
20	22.54	23.8	27
21	22.77	23.98	28
22	23.16	24.25	1
23	22.56	24.56	29
24	22.92	25.11	9
25	23.18	25.14	30
26	22.67	25.18	31
27	23.8	25.64	10
28	23.98	25.99	12
29	24.56	26.22	11
30	25.14	26.35	14
31	25.18	26.42	13

Table A2. *Sorted daily and long term* ***mean temperature*** *for* ***January*** *of the selected years*

					Selected Year Number (Mean Temperature)						
Day	**14 th**	**Day**	**19th**	**Day**	**4th**	**Day**	**8th**	**Day**	**13th**	**Long-Term Average**	
31	19.23	12	19.14	8	20.71	1	19.79	1	22.02	22.607	
23	20.19	13	19.48	9	20.75	2	20.84	9	22.19	22.661	
30	20.55	4	20.56	7	20.97	3	21.56	10	22.21	22.732	
24	20.78	30	20.59	10	21.12	4	22.05	2	22.28	22.754	
22	20.85	29	20.68	11	22.61	13	22.37	11	22.46	22.773	
25	21.31	14	20.71	2	22.83	14	22.70	3	22.52	22.784	
21	21.89	31	20.75	27	22.93	15	23.35	12	22.68	22.828	
27	21.98	15	20.96	28	23.04	12	23.48	8	22.93	22.847	
29	22.06	16	20.98	1	23.08	22	23.71	14	22.98	22.927	
28	22.26	11	21.05	6	23.13	5	23.79	7	23.13	22.927	*33rd*
26	22.26	28	21.11	12	23.22	6	23.97	5	23.16	22.973	*percentile*
2	22.52	3	21.24	26	23.41	11	24.31	6	23.21	22.980	
3	23.00	17	21.51	25	23.49	21	24.53	17	23.28	23.093	
20	23.46	2	21.64	3	23.66	16	24.55	13	23.33	23.142	
4	23.95	5	21.69	30	24.17	17	24.88	18	23.48	23.191	*Median*
1	24.19	27	21.98	29	24.25	20	24.99	4	23.71	23.403	
5	24.46	18	22.73	4	24.30	8	25.00	16	23.75	23.482	
19	24.81	10	22.95	15	24.34	19	25.12	20	23.78	23.746	
6	25.05	26	22.97	24	24.70	7	25.16	15	23.80	24.133	
10	25.30	1	23.03	31	24.85	18	25.39	19	24.17	24.206	
18	25.41	24	23.10	16	24.88	10	25.45	21	25.40	24.300	*67th*
14	25.51	25	23.45	13	25.16	9	25.64	24	25.57	24.318	*percentile*
11	25.58	6	23.65	14	25.27	31	25.75	30	25.71	24.498	
15	25.75	23	23.69	5	25.64	27	25.86	31	26.35	24.502	
17	26.05	9	23.94	17	25.97	28	25.87	25	26.39	24.546	
7	26.22	22	24.79	20	26.30	30	25.92	26	26.84	24.609	
13	26.44	7	24.96	19	26.54	23	25.98	22	26.85	24.613	
12	26.61	8	25.14	18	26.61	26	26.25	29	26.86	24.689	
9	26.62	19	25.61	23	26.98	25	26.78	23	26.98	24.705	
16	26.70	21	26.10	21	27.03	29	26.89	28	27.75	24.784	
8	26.92	20	26.92	22	27.40	24	27.18	27	27.99	24.870	
Median	**24.19**		**21.98**		**24.25**		**24.99**		**23.71**	**23.40**	
Mean	**23.80**		**22.49**		**24.17**		**24.49**		**24.31**	**23.63**	
33rd	**22.26**		**21.10**		**23.21**		**23.95**		**23.16**		
67th	**25.42**		**23.14**		**24.91**		**25.47**		**25.42**		
Diff 1	**0.17**		**1.15**		**0.54**		**0.85**		**0.68**		
Diff 2	**0.79**		**1.42**		**0.85**		**1.59**		**0.31**		

Diff 1 = |Short-term median – Long-term median|
Diff 2 = |Short-term mean – Long-term mean|

Table A3. *Sorted daily mean and long-term* ***global radiation*** *for* ***January*** *of the selected years*

					Selected Year Number (Global Radiation)						
Day	**14 th**	**Day**	**19 th**	**Day**	**4 th**	**Day**	**8 th**	**Day**	**13 th**	**Long-Term Average**	
22	17.68	7	16.09	5	18.43	5	17.86	3	17.14	19.035	
4	17.82	6	18.25	4	18.72	8	17.86	4	17.46	19.221	
5	17.89	11	18.29	3	19.22	29	18.22	1	17.53	19.105	
20	18.00	4	18.72	1	19.30	9	18.90	10	17.60	19.224	
3	18.11	3	18.72	11	19.51	2	19.12	6	17.60	19.067	
23	18.32	9	18.86	10	19.66	6	19.19	9	17.71	18.875	
2	18.43	8	18.86	8	19.73	17	19.58	2	17.75	18.959	
24	18.50	13	19.01	7	19.73	3	19.66	20	17.78	18.980	
18	18.58	2	19.12	9	19.80	1	19.80	11	17.82	19.348	
7	18.61	1	19.19	2	19.84	12	20.09	8	17.82	19.074	*33rd*
9	19.04	12	19.22	21	20.02	10	20.09	5	17.93	18.970	*percentile*
19	19.08	5	19.33	6	20.05	27	20.12	12	18.07	18.618	
6	19.40	29	19.44	17	20.23	23	20.16	13	18.07	19.337	
21	19.48	31	19.73	18	20.23	4	20.20	19	18.22	19.689	
30	19.62	19	19.80	19	20.30	19	20.20	21	19.08	19.894	*Median*
27	19.62	16	19.84	16	20.34	20	20.27	7	19.15	19.132	
28	19.66	20	19.87	14	20.34	15	20.30	25	19.33	19.496	
29	19.87	17	19.94	15	20.45	16	20.34	16	19.51	20.187	
11	19.94	14	20.02	13	20.45	7	20.45	24	19.73	19.825	
16	20.05	10	20.02	12	20.59	26	20.48	14	19.87	19.899	
26	20.09	15	20.12	22	20.70	13	20.52	22	19.94	19.797	*67th*
8	20.27	18	20.16	20	20.74	14	20.52	15	20.30	20.180	*percentile*
17	20.30	21	20.34	28	20.84	11	20.74	26	20.56	20.384	
31	20.41	28	20.45	23	21.02	21	20.77	17	20.84	20.329	
10	20.45	22	20.48	24	21.10	28	20.81	29	20.88	20.379	
25	20.48	25	20.70	25	21.20	22	20.88	30	20.99	20.514	
12	20.63	24	20.84	30	21.35	25	20.92	27	21.02	20.694	
14	20.77	26	20.88	31	21.53	18	21.06	28	21.06	20.498	
1	20.84	23	21.10	27	21.60	24	21.06	18	21.20	20.589	
13	21.06	30	21.24	26	21.60	30	22.03	31	21.20	21.110	
15	21.31	27	21.35	29	21.78	31	22.36	23	21.71	21.191	
Median	**19.62**	**19.84**		**20.34**		**20.27**		**19.15**		**19.689**	
Mean	**19.49**	**19.68**		**20.34**		**20.15**		**19.19**		**19.729**	
33rd	**19.00**	**19.22**		**20.00**		**20.09**		**17.92**			
67th	**20.11**	**20.13**		**20.70**		**20.52**		**19.98**			
Diff 1	**0.23**	**0.05**		**0.61**		**0.42**		**0.54**			
Diff 2	**0.07**	**0.15**		**0.65**		**0.58**		**0.54**			

Diff 1 = |Short-term median – Long-term median|
Diff 2 = |Short-term mean – Long-term mean|

Table A4. *For each of the five selected months (five January months), the difference between the long-term and short-term daily means and medians for temperature and solar flux*

	Mean Temperature		*Global Radiation*			Sorted	Year
Year #	**Mean**	**Media**	**Mean**	**Median**	**Max**	**Max**	**Number**
14	0.1706	**0.7874**	0.2344	0.0689	0.7874	0.6819	13
19	1.1459	**1.4226**	0.0521	0.1471	1.4226	0.7874	14
4	0.5393	**0.8474**	0.6063	0.6511	0.8474	0.8474	4
8	0.8545	**1.5874**	0.4171	0.5791	1.5874	1.4226	19
13	**0.6819**	0.3074	0.5387	0.5369	0.6819	1.5874	8

Table A5. *The selected candidate year number (1–23 stands for 1994–2016) for the months of the typical year*

Months											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
13	15	19	11	16	8	23	11	19	12	22	13
14	9	11	16	15	15	20	9	6	8	17	1
4	4	12	21	17	13	18	6	13	20	6	4
19	12	17	19	19	4	16	12	14	11	16	18
8	13	13	17	18	7	13	7	10	14	15	16

Table A6. *The number and lengths of the first month's runs (for both temperature and solar flux parameters, January of year number 4, i.e. 1997)*

Considering Year no 4 (1997)

Order	Temperature		Order	Global Radiation	
8	20.71	Run Length of 2	5	18.43	Run Length of 3
9	20.75		4	18.72	
7	20.97		3	19.22	
10	21.12	Run Length of 2	1	19.30	
11	22.61		11	19.51	Run Length of 2
2	22.83		10	19.66	
27	22.93	Run Length of 2	8	19.73	Run Length of 2
28	23.04		7	19.73	
1	23.08		9	19.80	
6	23.13		2	19.84	
12	23.22		21	20.02	
26	23.41		6	20.05	
25	23.49		17	20.23	
3	23.66		18	20.23	
30	24.17		19	20.30	
29	24.25		16	20.34	
4	24.30		14	20.34	
15	24.34		15	20.45	
24	24.70		13	20.45	
31	24.85		12	20.59	
16	24.88		22	20.70	
13	25.16	Run Length of 2	20	20.74	
14	25.27		28	20.84	
5	25.64		23	21.02	Run Length of 3
17	25.97		24	21.10	
20	26.30	Run Length of 3	25	21.20	
19	26.54		30	21.35	Run Length of 2
18	26.61		31	21.53	
23	26.98		27	21.60	Run Length of 2
21	27.03	Run Length of 2	26	21.60	
22	27.40		29	21.78	

Temperature: Number of runs = **6 ;** Maximum run length = **3**
Global Radiation: Number of runs = **6 ;** Maximum run length = **3**
Total = 12 ; **Max = 6**

Table A7. *The number and lengths of the runs of the months of January and December for the years selected*

January			***December***		
Year	Number of Runs	Max Run Length	Year No	Number of Runs	Max Run Length
13	7	4	13	5	5
14	2	4	1	4	5
4	12	6	4	7	4
19	10	4	18	5	5
8	5	6	16	7	4

Table A8. *The corresponding years of the candidate months and their indices (0 or 1) for the months of January through December*

Month											
Jan	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
13(1)	15(1)	19(1)	11(1)	16(1)	8(0)	23(1)	11(1)	19(0)	12(0)	22(1)	13(1)
14(1)	9(1)	11(1)	16(1)	15(1)	15(1)	20(1)	9(1)	6(1)	8(1)	17(1)	1(1)
4(0)	4(1)	12(0)	21(0)	17(0)	13(1)	18(0)	6(0)	13(0)	20(1)	6(0)	4(1)
19(1)	12(0)	17(1)	19(0)	19(1)	4(0)	16(0)	12(1)	14(1)	11(0)	16(0)	18(0)
8(0)	13(0)	13(0)	17(0)	18(0)	7(1)	13(1)	7(0)	10(0)	14(1)	15(1)	16(0)

Table A9. *Summary of TMY for Sokoto*

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The month of JANUARY of TMY is selected from year        2006
The month of FEBRUARY of TMY is selected from year       2008
The month of MARCH of TMY is selected from year          2012
The month of APRIL of TMY is selected from year          2004
The month of MAY of TMY is selected from year            2009
The month of JUNE of TMY is selected from year           2008
The month of JULY of TMY is selected from year           2016
The month of AUGUST of TMY is selected from year         2004
The month of SEPTEMBER of TMY is selected from year      1999
The month of OCTOBER of TMY is selected from year        2001
The month of NOVEMBER of TMY is selected from year       2015
The month of DECEMBER of TMY is selected from year       2006
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