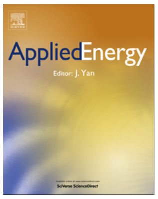
Applied Energy 112 (2013) 152–159

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



Generation of a typical meteorological year for north–east, Nigeria

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HIGHLIGHTS

- TMY for sites in north–east Nigeria was produced using Finkelstein–Schafer method.
- It was found the TMY can be used to represents the long-term weather parameters.
- The generated TMY can be used the design and evaluation of solar energy systems.
- A handy database in the estimation of building heating loads in north–east Nigeria.

ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form 15 May 2013
Accepted 27 May 2013
Available online 29 June 2013

Keywords:
Typical meteorological years
Finkelstein–Schafer statistical method
Global solar radiation
Dry bulb temperatures
Nigeria

ABSTRACT

The Finkelstein–Schafer statistical method was applied to analyze a 34-year period (1975–2008) hourly measured weather data which includes global solar radiation, dry bulb temperatures, precipitation, relative humidity and wind speed in order to generate typical meteorological year (TMY) for five locations spreading across north–east zone, Nigeria. The selection criteria are based on solar radiation together with the dry bulb temperature values and representative typical meteorological months (TMMs) were selected by choosing the one with the smallest deviation from the long-term cumulative distribution function. A close-fit agreement is observed between the generated TMY and long-term averages. The TMY generated will be very useful for optimal design and performance evaluation of solar energy conversion systems, heating, ventilation, and air conditioning (HVAC) and other solar energy dependent systems to be located in this part of Nigeria.

1. Introduction

The rapid growth of industrialization and world population that led to the increase in energy demand, depletion of finite fossil fuel resources and climate change have made renewable energy resources increasingly attractive as alternative to continued over-dependence on conventional energy sources. Presently, access to electric power in Nigeria has been generally low. This is due to fluctuations in the availability and maintenance of production sources leading to a shortfall in supply. The current peak electricity generation in Nigeria is about 4362 MW which is about 43% of the current forecasted peak demand for electricity in the country [1]. According to World Bank 2012 report, the average electricity consumption per capital as at 2009 in Nigeria is 120.5 kW h per year which is less than 2 kW h per day for a household of five people. This has made access to reliable and stable supply of electricity a major challenge for both the urban and rural dwellers in Nigeria. However, the challenge is more significant in the rural areas where only about 10% of the population has access to electricity [2]. It is reported that about 51% of the entire populace reside in remote or rural areas, that have little or no access to electricity. According to Hermann [3], lack of or inadequacy of energy in an economy is a potential source of social and economic poverty.

Renewable energy sources (wind, solar, hydropower, etc.) are inexhaustible, clean, free and offer many environmental and economic benefits; accurate assessment of weather data is thus vital in the choice of a profitable location for proper harvest of any of these energy sources. In order to reduce the computational efforts in simulation and weather data handling, it is now common to adopt one year (or 'typical year') of weather data instead of multiple years, which can represent the long-term weather data. Forms of typical years exist as typical meteorological year (TMY), test reference year (TRY), weather year for energy calculations (WYEC), International Weather Year for Energy Calculation (IWEC) and typical principal component year (TPCY) [e.g., 4–8]. According to Skeiker and Abdul Ghani [9], the term "typicality" could be interpreted in many ways: to some users of solar and building energy

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http://dx.doi.org/10.1016/j.apenergy.2013.05.072

simulations, "typicality" has to do with the selection of weather, which appears to be typical of an appropriate portion of the year. Others have selected a year, which appears to be typical from several years of solar radiation data, and some investigators have run long periods of observational data in an attempt to simulate typical weather for the calculation.

Of all the various types of typical year databases, the common typical years are the TRY and the TMY [10]. However, the major shortcoming of TRY is that the selection process of the typical year result in a mild year that eliminates extreme conditions [8,11] and hence, the selected year may not be considered good enough to represent the prevailing mean weather conditions over a long-term period [10] and should be avoided [11]. In addition, building energy simulation runs using TRY weather data were unusually less dependable in representing average historical or long-term conditions [8]. As a result of these shortcomings of TRY, Crawley [11] recommended that methods that produces a synthetic year (for instance, TMY) to represent the meteorological data within the period of record are better and hence, should be used for energy simulations.

TMY has been developed using several methods in literatures [12–19], all targeted at selecting single months or years from a long-term typical weather condition. The Sandia method developed using the Filkenstein–Schafer (FS) statistical analysis is adopted in this work with selection criteria based on solar radiation together with the dry bulb temperature values. Even though, TMY has been developed in many regions/countries (such as Ankara, Athens, Belgium, Italy, Spain, Canada, Damascus, Japan, China, Nicorsia, Saudi Arabia, Hong Kong, and Macau), the concept is not widely developed in Nigeria, only scanty work had so far been carried out on few locations across the country viz: TRY generation for Ibadan [20], TMY for Port-Harcourt zone [21] and TMY generation for Sokoto [22]. It should be mentioned that TRY for Ibadan as presented by Fagbenle [20] only focused on global solar radiation and for selection of each month, the year with minimum value of FS is selected.

The aim of this work is therefore to develop TMY across the north–east region of Nigeria using long duration hourly data captured at the selected locations within the region viz: Bauchi, Ibi, Nguru, Potiskum and Yola. The geographical coordinates of these cities are presented in Table 1. The meteorological data (global solar radiation, dry-bulb temperature (mean, maximum and minimum), relative humidity, precipitation, and wind speeds) captured by the Nigeria Meteorological Agency (NIMET) located at Oshodi, Nigeria were used.

Among other factors, these parameters (global solar radiation, dry-bulb temperature (mean, maximum and minimum), relative humidity, precipitation, and wind speeds) were chosen due to their impact on (and significant contribution to) the solar energy systems performance, and heat gain and loss in buildings. For instance, in building applications, the knowledge of solar radiation is vital for accurate determination of cooling load (in tropical and sub-tropical regions) and heating load (in temperate regions). It should be noted that the air ambient temperature influences the thermal response of a building and the amount of heat gain and loss through it, so also wind speed and direction can affect the rate of heat gain or loss through building walls by convection. The relative humidity is essential for the determination of latent heat for air-conditioning systems and evaporation levels [23]. In addition, precipitation can affect the ambient conditions (e.g. air temperature) and hence, the heat gain or loss through the building. For solar energy conversion systems (Concentrating Solar Power system and Photovoltaic system), these meteorological data are also essential for design, selection and performance evaluation of these systems. It should be mentioned that high precipitation can also help in reducing (cleaning) dust accumulation on solar energy conversion systems, such as PV [24].

2. Methods

2.1. Data treatment

The 34 year hourly data of the selected parameters are subjected to relevant treatment before being used for the TMY generation. Smoothing of data for discontinuities in situation of missing and/or invalid data is usually required to avoid abrupt changes at the boundary between two adjacent months selected from different years. The technique adopted in Zang [25] were used in this study for missing and/or invalid data measurements as witnessed in the data acquired from NIMET for the selected sites in Table 1. Missing data that are less than five days in a month are replaced with values of preceding or subsequent days by interpolation and these accounts for approximately 0.96% of the database in the whole region. However, in situation of non-availability of data for more than five days in a month, the whole month is excluded completely from further analysis. After successful treatment, the general 34 year long duration hourly data are reduced to between 28 and 33 years for the different locations as indicated in Table 1.

2.2. TMY procedure

The approach adopted for selecting TMYs for a given zone is as follows: a typical month for each of the twelve calendar months from the long-term data base was chosen and then those 12 months TMMs are concatenated to form TMYs. Monthly statistics were calculated for each index. Month/year combinations which had statistics that were 'close' to the long-term statistics, were candidates for typical months. TMM selection procedure consisted of two steps: (i) selection of five candidate years that are closest to the composites of all the years under study for each of the twelve calendar month, and (ii) selection of the TMM from the candidate years.

2.3. Statistical analysis and selection of five candidate years

As mentioned previously, seven weather parameters (or indices) were used for the statistical analysis. In [8,22], each of the seven sets of daily indices are sorted into bins by month and are then used to establish 12 long-term cumulative distribution functions (CDFs). According to Skeiker and Abdul Ghani [9], if a number n of observations of a variable x are available and have been sorted into an increasing order $x_1, x_2, \ldots x_n$, the CDF of this variable is given by a function $S_n(x)$, which is defined as follows:

Table 1
Geographical locations of the sites used for this study.

Locations	Data period	Latitude (°N)	Longitude (°E)	Elevation (m)
Bauchi	1978–1996, 1999–2008	10.17	09.49	609.7
Ibi	1978–2007	08.11	09.45	110.7
Nguru	1975–2007	12.53	10.28	343.1
Potiskum	1975–1981, 1983–2006	11.42	11.02	414.8
Yola	1975–2004	09.14	12.28	186.1

Table 2
Weighting factors assigned for the respective weather indices.

Parameter	Weight (W_j)
Global solar radiation	5/12
Dry bulb temperature (mean)	2/12
Dry bulb temperature (maximum)	1/12
Dry bulb temperature (minimum)	1/12
Precipitation	1/12
Relative humidity	1/12
Wind speed	1/12

$$S_n(x) = \begin{cases} 0 & x < x(1), \\ (k-0.5)/n & x(k) \le x \le x(k+1), \\ 1 & x \ge (n) \end{cases} \tag{1}$$

where $S_n(x)$ is the value of the CDF at x, n is the total number of elements, while k is ranked order number ($k = 1, 2, 3, \ldots n-1$).

The statistics selected to measure the closeness of each year's CDF to the long-term composite for a given index was the FS statistic, given in Eq. (2) as:

$$FS_j = \frac{1}{n}\sum_{i=1}^{n}\delta_i, \quad i = 1, 2, \ldots n \tag{2}$$

where δ_i is the difference between the short-term and the long-term CDFs for day i in the month, n = number of days in the month and j is the parameter (index) considered. The smaller the value of FS, the closer the fit of the two CDFs and therefore, the more the TMY resembles the long-term data. It should be noted that a zero value of FS statistic indicates identical means, averaged standard deviations and distributions between the TMY and long-term data [26]. For each of the candidate months, the seven different FS statistics calculated for the seven indices are grouped into a composite weighted index using Eq. (3) [27] together with the weighting factors listed in Table 2; the resulting product gives the weighted sum (WS).

$$WS = \sum_{j=1}^{n} W_j FS_j \tag{3}$$

where n = number of indices (parameters/elements) considered, W_j = weight for index j, and FS_j = FS statistic for index j.

The assignment of weighting indices is mainly intuitive and primarily depends on the intended applications of the generated TMY. In this study, a weighting index of 5/12 (usually between 40% and 50% for solar application (Jiang [28])) is assigned to global solar radiation and 2/12 is assigned to the mean ambient temperature, while other weather indices were given equal weights that add up to 5/12. This higher value assigned to global solar radiation is because (i) these methods are mainly used for solar energy systems, (ii) in tropical regions with warm weather (like Nigeria), solar heat gain can be more significant in cooling load calculations for

Table 3
Weighting factors of the weather indices for FS-statistics for Ibi.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978	*1.879*	2.724	2.493	3.182	3.208	*2.389*	3.197	3.415	2.769	2.605	2.425	2.077
1979	*1.736*	2.708	*2.006*	2.611	*2.519*	*2.392*	*2.411*	*2.581*	*2.413*	2.341	2.447	2.337
1980	2.439	*2.045*	2.848	2.527	*2.343*	2.734	*2.396*	2.792	3.268	2.795	2.245	3.008
1981	3.205	2.588	*2.036*	2.575	3.252	3.259	3.139	3.010	2.733	2.149	2.982	*1.918*
1982	2.603	2.820	2.396	2.282	3.140	*2.559*	2.828	*2.545*	2.933	*1.987*	2.678	2.368
1983	3.354	2.689	3.575	3.098	2.994	3.012	3.308	*2.533*	*2.547*	2.047	1.923	3.088
1984	2.899	*2.423*	2.228	2.458	2.864	2.728	3.462	3.009	2.804	2.320	2.275	2.657
1985	3.104	3.039	3.247	2.856	*2.648*	3.521	2.912	3.505	*2.623*	2.209	1.911	2.994
1986	2.305	2.673	2.310	*2.271*	3.604	2.921	2.823	2.904	2.777	2.799	1.928	2.768
1987	2.523	2.666	2.785	3.741	4.076	3.293	2.640	2.865	2.809	*1.985*	1.929	2.481
1988	2.692	2.638	3.162	2.815	3.541	*2.476*	2.836	3.183	2.973	2.660	2.458	2.696
1989	2.359	3.067	2.813	2.859	3.409	2.892	3.111	2.758	3.261	2.311	*1.873*	*1.857*
1990	2.659	2.661	3.819	2.619	3.182	3.309	2.803	3.236	2.925	2.337	2.585	4.326
1991	2.067	2.967	2.339	3.259	3.229	2.843	*2.412*	3.008	3.253	2.046	2.134	2.397
1992	2.657	2.638	4.403	2.874	2.781	2.902	2.692	*2.624*	2.916	2.506	2.359	2.027
1993	2.179	2.617	3.268	2.712	3.459	3.772	2.933	3.112	3.031	*1.984*	4.034	1.952
1994	2.729	2.480	*1.969*	3.325	2.890	2.784	3.212	2.839	*2.605*	2.941	2.279	2.334
1995	*1.913*	*2.205*	2.472	2.665	2.846	3.382	3.065	3.223	*2.164*	2.519	2.290	*1.868*
1996	2.522	2.803	2.763	3.670	3.104	3.132	3.049	2.812	3.598	2.530	2.832	2.024
1997	2.569	2.525	2.480	2.874	2.823	2.762	2.613	2.984	3.315	2.551	2.963	2.221
1998	2.733	3.164	2.982	2.887	*2.689*	2.992	2.941	3.341	2.942	2.356	*1.798*	*1.809*
1999	2.053	3.102	2.153	*2.255*	2.842	3.152	*2.379*	3.078	3.061	2.299	1.981	*1.764*
2000	2.476	2.816	2.624	*2.181*	3.053	3.027	2.668	*2.685*	2.989	*1.905*	2.269	2.275
2001	*1.914*	*2.266*	*1.940*	*2.115*	3.011	2.858	3.112	3.255	3.395	2.074	2.071	2.216
2002	*1.567*	*2.466*	*1.970*	3.321	*2.656*	3.148	2.769	3.196	3.346	2.489	*1.897*	2.398
2003	2.689	2.513	2.485	5.211	3.794	2.955	4.860	2.793	3.165	2.223	*1.904*	2.235
2004	2.203	2.686	3.507	3.177	3.478	3.656	3.170	2.828	3.606	2.559	2.464	2.113
2005	3.082	3.461	2.451	2.468	3.364	2.893	3.786	3.592	3.150	*1.979*	2.264	2.029
2006	2.968	3.111	2.569	3.439	3.281	*2.587*	*2.483*	3.084	2.892	2.139	2.777	2.122
2007	1.930	2.829	2.336	*2.241*	2.925	3.184	3.356	3.391	3.240	2.452	*1.873*	2.543

Five years that have smallest weighed sum of the FS statistics of the seven daily indices for each month are shown in italic.

Table 4
TMYs of the selected locations in north–east, Nigeria.

Station	Month											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Bauchi	1986	1984	1986	1984	1979	1999	2007	1999	1979	1982	1985	1978
Ibi	2002	2007	2007	1978	1979	1978	1979	1983	1978	1978	2007	1999
Nguru	2007	1975	2002	2005	2002	2004	2003	2003	2003	2007	1989	1996
Potiskum	2006	2006	1976	1999	2008	2006	1976	2006	2006	1983	2005	1975
Yola	1986	1975	1975	1975	1975	1978	1997	1998	1983	1975	1985	1997

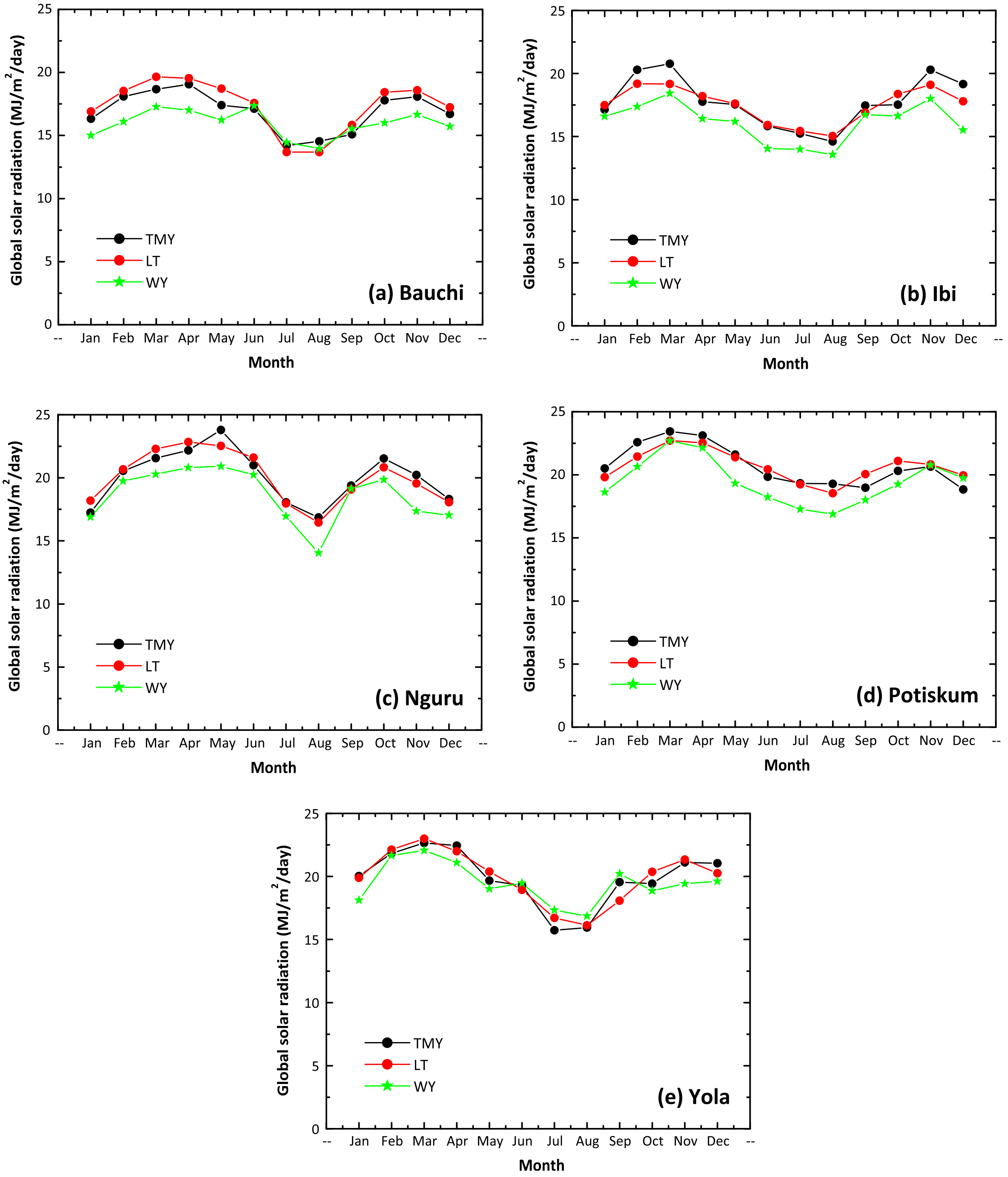

Fig. 1. The monthly mean values of the TMY, worst years and the average long-term global solar radiations for: (a) Bauchi, (b) Ibi, (c) Nguru, (d) Potiskum and (e) Yola.

building as well as for passive and active heating systems and, (iii) other weather parameters are directly or indirectly affected by global solar radiation. Five years are thus selected, having the smallest weighed sum of the FS statistics of the seven daily indices (global solar radiation, mean dry bulb temperature, minimum temperature, maximum temperature, relative humidity, precipitation and wind speed) for each month of the calendar year. The values of WS (for example, Ibi) for the 34 years examined for all months and the 5 selected years (underlined and highlighted) are presented in Table 3.

2.4. Selection of TMM

After generating WS for each individual month for the respective site under consideration, the following steps are followed in arriving at values needed for the TMY according to Chan et al. [8]:

- The five candidate years are ranked in ascending order of the WS values.
- A typical month is then selected by choosing from among the five, months with the lowest WS values.
- The persistence of mean dry bulb temperature and daily global horizontal radiation are evaluated by determining the frequency and run length above and below fixed long-term percentiles.
  - For mean daily dry bulb temperature, the frequency and run length above the 67th percentile and below the 33rd percentile are determined.
  - For global horizontal radiation, the frequency and run length below the 33rd percentile are also determined.
- The persistence data are used to select from the five candidate months, the month to be used in the TMY. The highest ranked candidate month in ascending order of the WS values that meet the persistence criterion is used in the TMY.

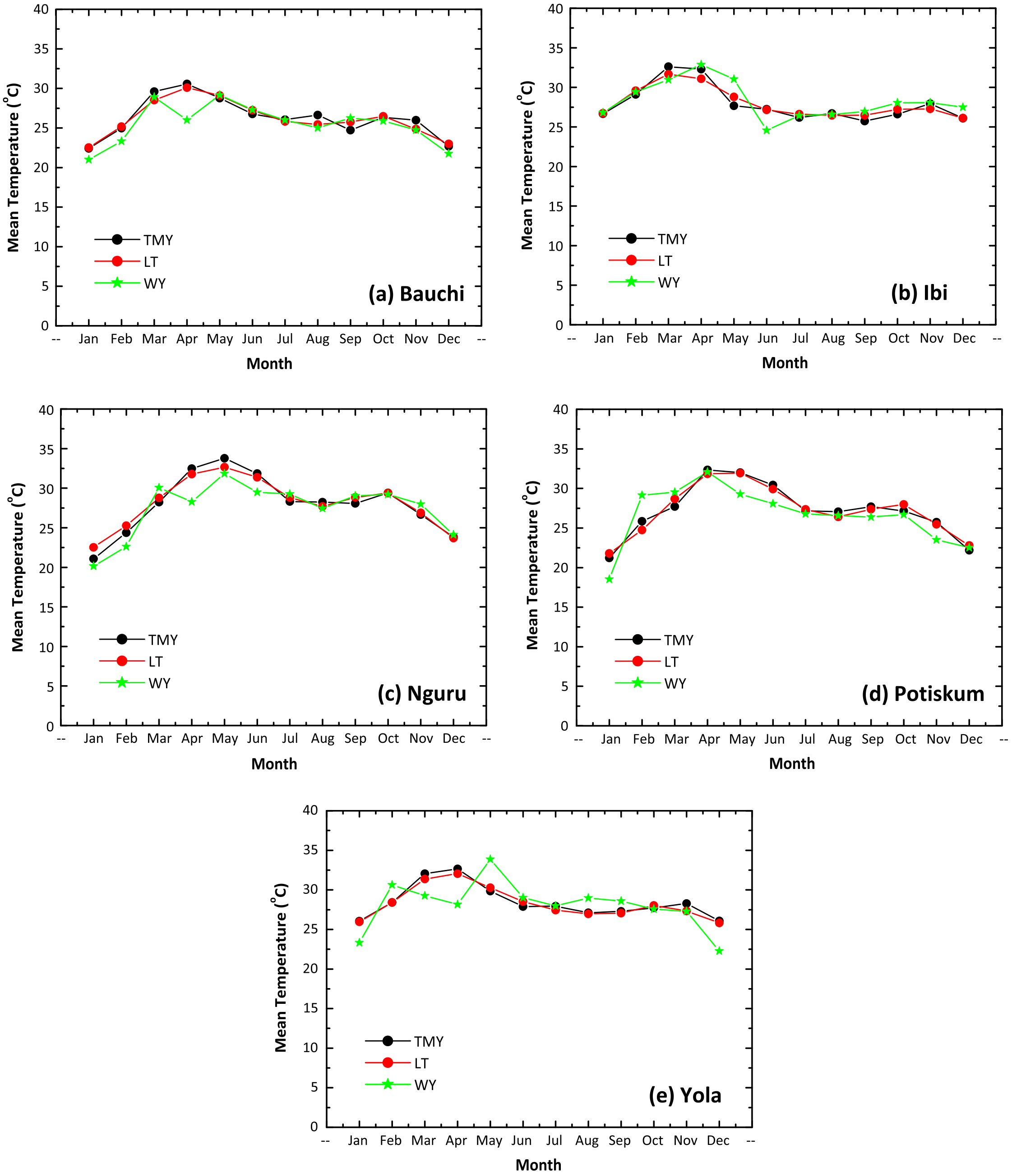

Fig. 2. The monthly mean TMY, worst years and the average long-term values of the mean temperature for: (a) Bauchi, (b) Ibi, (c) Nguru, (d) Potiskum and (e) Yola.

2.5. Mean percentage error

The performance of the TMY was investigated using methods of stochastic analysis to calculate the mean percentage error (MPE). MPE was adopted as it is often preferred for long term performance of the examined relations. MPE is commonly used to evaluate cross-sectional forecasts. It has valuable statistical properties in that it makes use of all observations and has the smallest variability from sample to sample [29]. It is expressed as:

$$\mathrm{MPE} = \frac{1}{n}\left[\sum\left(\frac{U_{\mathrm{LT}} - U_{\mathrm{TMY}}}{U_{\mathrm{LT}}} \times 100\right)\right] \tag{4}$$

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

3. Results and discussion

The results of the TMY selections of the seven locations are shown in Table 4. The TMMs are determined based on their being able to follow the long term frequency distributions. Besides frequency of occurrence, it would be useful to compare the actual daily or monthly values, especially for mean dry bulb temperature and global solar radiation, and see whether the TMMs selected do show good agreement with the long-term data. The FS statistics for individual weather index were examined and found to differ from one index to another and also vary between months. The persistence of mean dry bulb temperatures and daily global solar radiation on horizontal surfaces for the five candidate months were evaluated by determining the frequency and run length above and below fixed percentiles (33rd and 67th) as discussed in Sawaqed et al. [27]. This was considered because it will definitely produce useful information needed for building energy

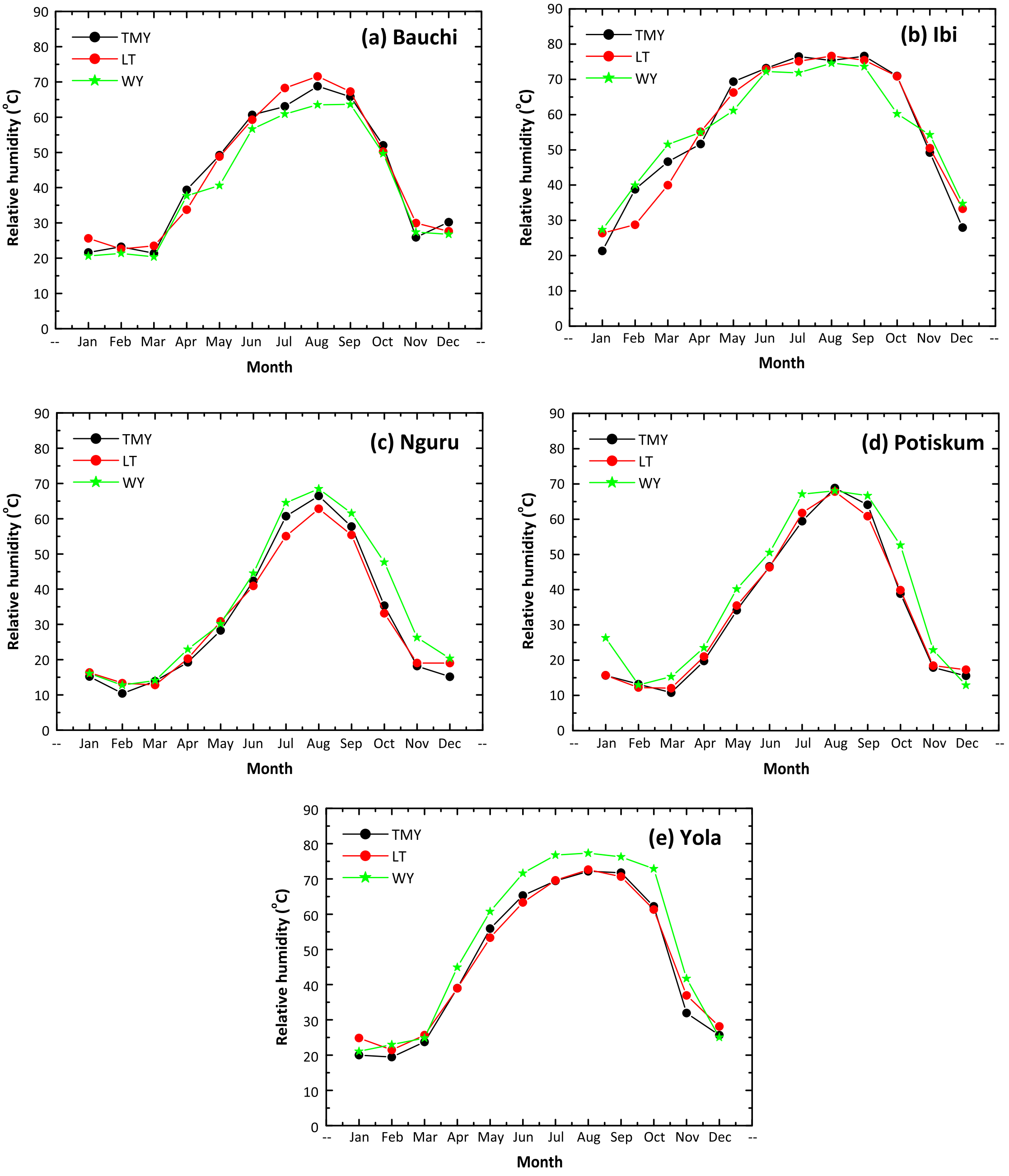

Fig. 3. The monthly mean TMY, worst years and the average long-term values of the relative humidity for: (a) Bauchi, (b) Ibi, (c) Nguru, (d) Potiskum and (e) Yola.

performance. The comparison between the generated TMY and long term averaged as well as selected year for chosen weather parameters are presented in Figs. 1–4 for all the sites.

The results of comparison of the monthly mean values of the global solar radiations are given for the TMY, worst years (composed of the worst months of the period, which are months having the farthest short-term cumulative distribution functions (CDFs) to the long-term cumulative distribution functions over all parameters (elements) CDFs) and the average long-term measurements within the selected sites as shown in Fig. 1. It can be observed that there is a similar trend with excellent relationships between the TMY and the long-term mean of the global solar radiation in all the selected sites. Even though the worst year (WY) follows similar trend to the long term and TMY curves, significant monthly deviation from the other curves can be observed in almost all the sites. The values computed for the selected locations peaked were 19.06 MJ/m^2/day in April, 17.30 (March) and 19.64 MJ/m^2/day (March) for the TMY, WY and long-term values respectively in Bauchi; the values at Ibi are 20.78 and 18.44 in March and 19.18 MJ/m^2/day in February; 23.79 and 20.92 MJ/m^2/day (May) and 22.85 in April at Nguru; 23.45, 22.69 and 22.72 MJ/m^2/day in March at Potiskum; TMY, WY and long-term average values, respectively.

The mean temperature curves of the selected locations for the TMY, worst year and long-term fluxes are presented in Fig. 2. Similar to solar radiation (Fig. 1), the mean temperature plots follows similar trends (Fig. 2), with all the sites having good fit between the TMY and long term average. Maximum values of the curves occurred in March, which is a dry season month across the region. Again, the worst year (WY) deviates significantly from the other curves in some months in all the sites.

Figs. 3 and 4 show the TMY, WY and long-term curves for the relative humidity and wind speed, respectively. Regular trend

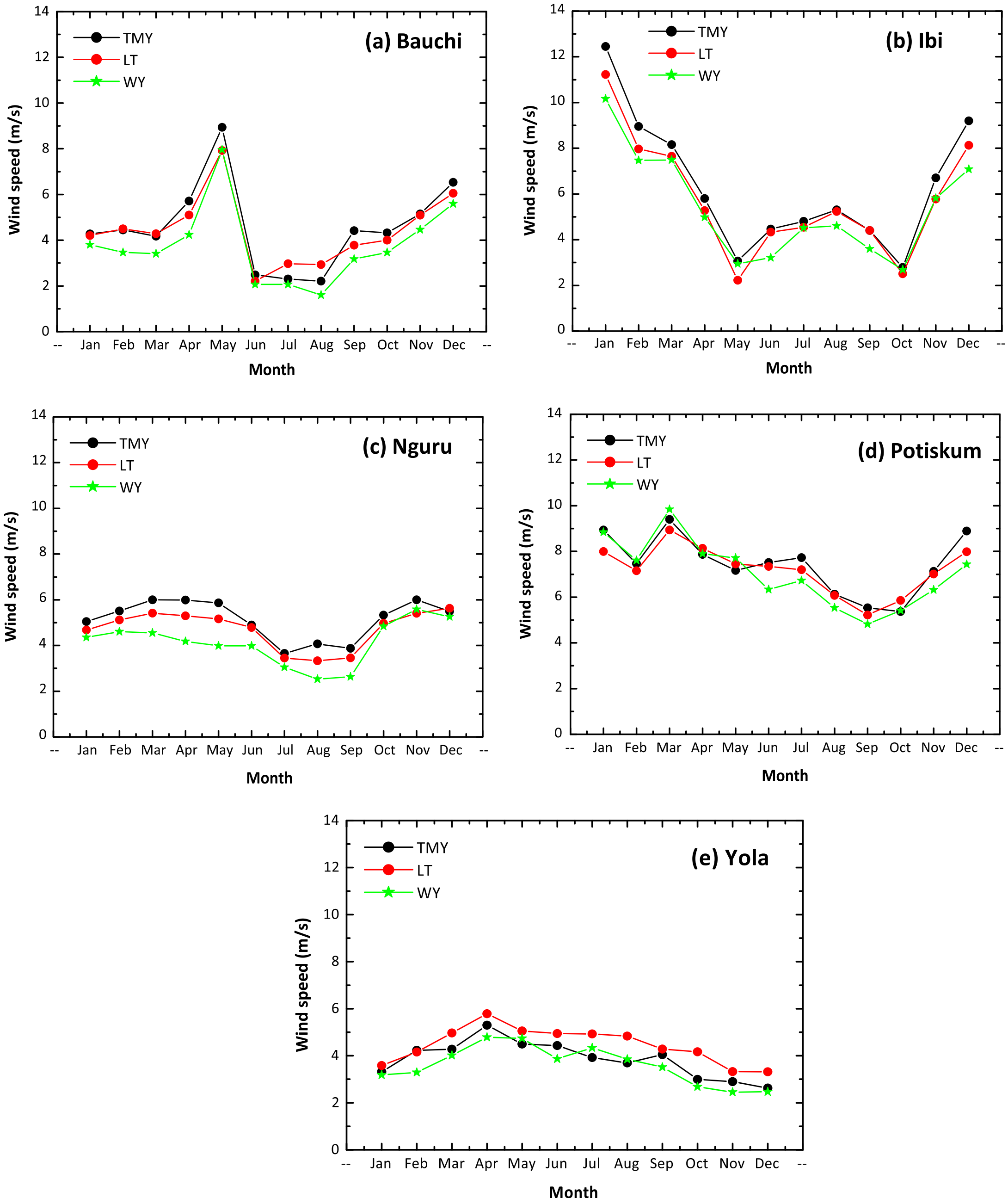

Fig. 4. The monthly mean TMY, worst years and the average long-term values of the wind speed for: (a) Bauchi, (b) Ibi, (c) Nguru, (d) Potiskum and (e) Yola.

Table 5
Comparison of MPE (%) of the long-term average values of indices with TMMs for the respective locations.

Locations	Mean percentage error, MPE (%)			
	Mean temperature	Global solar radiation	Wind speed	Relative humidity
Bauchi	−0.45	2.23	−1.83	1.39
Ibi	0.17	−1.45	−10.67	−1.18
Nguru	0.62	−0.28	20.17	2.42
Potiskum	−0.04	−0.12	−2.95	2.04
Yola	−0.60	0.20	13.41	4.03

can be observed with relative humidity (Fig. 3) throughout the region considered. However, slightly wide variation can be noticed in Bauchi and Yola with more prevalence during the rainy season for the TMY, WY and long-term averages; all curves are also found to peak between July and September in all the sites. Similarly, regular trend exist in the wind speed pattern across the zone for the TMY and long-term mean values (Fig. 4). Similar to the solar radiation and mean temperature plots, the worst year (WY) deviates significantly from the other curves in some months in all the sites for these two parameters. In addition, the degree of closed-fit between the TMY and long-term average for the relative humidity and wind speed is less when compared with solar radiation and dry-bulb temperature data. This observation may due to non-uniformity of the weighting factors and the selection of the TMMs which was based on persistence of mean temperature and daily global radiation.

In addition to the graphical comparison, the deviation of the TMY from the long-term average was estimated using mean percentage error (MPE) so that the degree of deviation of the TMY from long-term averaged can be quantified. Table 5 shows MPE results of all sites and for main weather parameters. A value of MPE represents an overall estimate of prediction bias between the TMY and long-term values, whereas the negative and positive values indicate respectively, under- and over-estimation of the TMY value when compared with the long-term average value. It can be observed from this table that variations of the monthly averaged mean dry bulb temperature TMMs are close to the long-term averaged in all the locations going by their respective MPEs (with values less than 1%). Also, the MPEs for TMY and long-term averaged are observed to be small with highest value of 2.23% (for Bauchi) and least value of −0.12% (for Potiskum) in the case of global solar radiation. The MPEs for wind speed and relative humidity indicates relatively high degree of deviation between the TMY and long-term means when compared with those for mean temperature and global solar radiation. As mentioned before, this disparity can be attributed to weighted factors applied to each weather parameters (which are bias toward mean temperature and global solar radiation).

The good fit between the TMY and long-term values as reported in this study, especially for the global solar radiation and mean dry-bulb temperature, is in agreement with findings of Anderson et al. [23] and Yang et al. [30]. Based on the performance of solar water heating system simulation [23] and building energy simulation [30], they reported that the key climatic variables of the TMYs followed closely their long term values and have a good statistical representation of the prevailing weather condition. It should be mentioned here that, in the advent of a changing climate, there is also the tendency of a reduction or increase in magnitude of weather parameters needed for weather data generation (most especially the global solar radiation and mean dry bulb temperatures that are found to be more prevalent in the chosen region); therefore a change in the selection of the typical weather years due to changing climate is thus inevitable [31].

4. Conclusion

The FS statistics technique was used to select 12 TMMs and then developed a TMY based on the most recent 34 years (1975–2008) measured weather data of five cities in north–east region Nigeria. This work represents a first step to developing a full TMY weather database for building heating loads and energy simulations in Nigeria. The following were concluded:

- The methodology implemented leads to acceptable results.
- The deviations of the TMY data from long term data are found to be small which shows that the generated TMYs can effectively be used instead of the long term averaged and hence, weather data processing and computation duration and space can be reduced for building and energy systems calculations.
- The result presented in this work can facilitate the design and performance evaluation of a solar energy conversion systems as well as a useful database in the determination of building heating loads in this part of Nigeria.

Acknowledgements

The authors are grateful to Nigerian Meteorological Agency (NIMET), Lagos, Nigeria for the data gathering and Space Applications and Environmental Science Laboratory (SPAEL), Atmospheric Studies and Space Applications Unit, Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile-Ife, Nigeria through whom we get the data for this study.

References

[1] Presidential Task Force on Power, <http://www.nigeriapowerreform.org/>; 2013 [accessed 04.01.13].
[2] Adaramola MS, Oyewola OM. Evaluating the performance of wind turbines in selected locations in Oyo state Nigeria. Renew Energy 2011;36(12):3297–304.
[3] Hermann S. A solar manifesto. London: James and James; 2001.
[4] Stamper E. Weather data. ASHRAE J 1997;19:47.
[5] Arens EA, Nall DH, Carroll WL. The representativeness of TRY data in predicting mean annual heating and cooling requirements. ASHRAE Trans 1979;85:707–21.
[6] Hall IJ, Prairie RR, Anderson HE, Boes EC. Generation of a typical meteorological year, In: Proceedings of the 1978 annual meeting of the American society of the international solar energy society, Denver; 1978. p. 641–45.
[7] Yang L, Wan KKW, Li DHW, Lam JC. A new method to develop typical weather years in different climates for building energy studies. Energy 2011;36(10):6121–9.
[8] Chan ALS, Chow TT, Fong SKF, Lin JZ. Generation of a typical meteorological year for Hong Kong. Energy Convers Manage 2006;47:87–96.
[9] Skeiker K, Abdul Ghani B. Advanced software tool for the creation of a typical meteorological year. Energy Convers Manage 2008;49:2581–7.
[10] Wong SL, Wan KKW, Li DHW, Lam JC. Generation of typical weather years with identified standard skies for Hong Kong. Build Environ 2012;56:321–8.
[11] Crawley DB. Which weather data should you use for energy simulations of commercial buildings? ASHRAE Trans 1998;104(Part 2). TO-98-2-2.
[12] Feuermann D, Gordon JM, Zarmi Y. A typical meteorological day "TMD" approach for predicting the long-term performance of solar energy systems. J Sol Energy 1985;35:193–208.
[13] Bahadori MN, Chamberlain MJ. A simplification of weather data to evaluate daily and monthly energy needs of residential buildings. Sol Energy 1986;36:499–507.
[14] Pissimanis D, Karras G, Notaridou V, Gavra K. The generation of a "Typical Meteorological Year" for the city of Athens. J Sol Energy 1988;40:405–11.
[15] Festa R, Ratto CF. Proposal of a numerical procedure to select reference years. Sol Energy 1993;50:9–17.
[16] Marion W, Urban K. User's manual for TMY2s typical meteorological years. Golden, CO, USA: National Renewable Energy Laboratory; 1995.
[17] Lam JC, Hui SCM, Chan ALS. A statistical approach to the development of a typical meteorological year for Hong Kong. Architect Sci Rev 1996;39:201–19.
[18] Petrakis M, Kambezidis HD, Lykoudis S, Adamopoulos AD, Kassomenos P, Michaelides IM. Generation of a typical meteorological year for Nicosia. Cyprus Renew Energy 1998;13:381–8.
[19] Janjai S, Deeyai P. Comparison of methods for generating typical meteorological year using meteorological data from a tropical environment. Appl Energy 2009;86:528–37.
[20] Fagbenle RL. Generation of a test reference year for Ibadan, Nigeria. Energy Convers Manage 1995;36:61–3.
[21] Oko COC, Ogoloma OB. Generation of a typical meteorological year for Port-Harcourt zone. J Eng Sci Technol 2011;6:204–21.
[22] Ohunakin OS, Adaramola MS, Oyewola OM, Fagbenle RL. A typical meteorological year generation for Sokoto, Nigeria. Proceedings of The Canadian Society for Mechanical Engineering International Congress 2012(June), p. 4–6. Winnipeg. Canada: Manitoba; 2012.
[23] Anderson TN, Duke M, Carson JK. A typical meteorological year for energy simulations in Hamilton, New Zealand. Transactions of Engineers New Zealand, Engineering TreNZ, 2007–003.
[24] Mani M, Pillai R. Impact of dust on solar photovoltaic (PV) performance research status challenges and recommendations. Renew Sust Energy Rev 2010;14(9):3124–31.
[25] Zang H, Xu Q, Du P, Ichiyanagi K. A modified method to generate typical meteorological years from the long-term weather database. Int J Photoenergy 2012. Article ID 538279.
[26] Freeman TL. Evaluation of the typical meteorological years for solar heating and cooling system studies. Technical Report (Final Report) Altas Corp., Santa Cruz, CA, USA; 1979.
[27] Sawaqed NM, Yousef H, Zurigat YH, Al-Hinai H. A step-by-step application of Sandia method in developing typical meteorological years for different locations in Oman. Int J Energy Res 2005;29:723–37.
[28] Jiang Y. Generation of typical meteorological year for different climates of China. Energy 2010;35(5):1946–53.
[29] Swanson DA, Tayman J, Bryan TM. MAPE-R: A rescaled measure of accuracy for cross-sectional forecasts, <http://cssd.ucr.edu/>; [accessed 08.02.13].
[30] Yang L, Lam JC, Liu J, Tsang CL. Building energy simulation using multi-years and typical meteorological years in different climates. Energy Convers Manage 2008;49(1):113–24.
[31] Li DHW, Yang L, Lam JC. Impact of climate change on energy use in the built environment in different climate zones – a review. Energy 2012;42(1):103–12.