ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2012. No. 7(123)
ELEKTRONIKA IR ELEKTROTECHNIKA

SYSTEM ENGINEERING, COMPUTER TECHNOLOGY
SISTEMŲ INŽINERIJA, KOMPIUTERINĖS TECHNOLOGIJOS

Development of TMY database in Northeast China for Solar Energy Applications

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crossref http://dx.doi.org/10.5755/j01.eee.123.7.2386

Introduction

To relieve the dual pressure from rising energy demand and growing environmental problems, renewable energy sources like solar energy are more favored. In this respect, solar radiation data, particularly typical solar radiation data, are the most basic and important parameters in many solar energy applications.

In the past, several approaches for generating TMYs have been proposed. These methods are similar–the main differences lie in the number of daily indices (weather parameters) to be included and their assigned weightings [1]. In the paper authored by Hall et al. [2], 13 meteorological indices were examined and 4 of the 13 indices were of very little importance so zero weightings were given to them. Said and Kadry [3] analyzed and researched seven weather indices and gave different weightings. Kalogirou [4] applied and selected 15 weather parameters. Moreover, Marion and Urban [5], Wilcox and Marion [6], Petrakis et al. [7] also made attempts to generate TMYs for different locations with respective weather parameters and assigned weighting factors.

In recent years, a few individual studies were performed to select the TMYs for different zones of China. Chow et al. [1] developed the typical weather year files for two neighboring cities, namely, Hong Kong and Macau. In the paper of Zhou et al. [8], typical solar radiation years and typical solar radiation data for 30 meteorological stations of China were produced only using the long-term daily global solar radiation records. Jiang [9] generated TMYs only for eight typical cities representing different climates of China, using nine weather parameters. Although a few attempts have been carried out on this subject, the work is going on or immature for China.

In this paper, in view of the actual situation in China, eight meteorological indices and novel assigned weighting factors are chosen and proposed in the procedure of forming TMY data. Based on the latest and accurate long term weather data and novel weighting factors, this paper generates the TMYs of eight cities for three provinces of Northeast China.

Region applied and data used

In China, the related weather data are recorded and managed by China meteorological stations. Attributing to new observation instrument, the relative errors of global solar radiation measured data in China meteorological stations are changed from ±10% to ±0.5% since 1993. The measured weather data at the eight stations are obtained over the periods between 1994 and 2009 in this study. The relevant information for the eight stations in the northeast three provinces of China is shown in Table 1.

Table 1. Geographical locations and data period

Province	Location	Latitude(N)	Longitude(E)	Elevation(m)	Period	Total years
Heilongjiang	Fuyu	47°48′	124°29′	162.7	1994-2009	16
	Harbin	45°45′	126°46′	142.3	1994-2009	16
	Kiamusze	46°49′	130°17′	81.2	1994-2009	16
Jilin	Changchun	43°54′	125°13′	236.8	1994-2009	16
	Yanji	42°53′	129°28′	176.8	1994-2009	16
Liaoning	Chaoyang	41°33′	120°27′	169.9	1994-2009	16
	Dalian	38°54′	121°38′	91.5	1994-2009	16
	Shenyang	41°44′	123°27′	44.7	1994-2009	16

Method used

The Typical meteorological year (TMY) method, which was developed by Sandia National Laboratories, is an empirical methodology for combining 12 typical meteorological months (TMMs) from different years to form a complete year. The process adopted to select the 12 typical weather months is illustrated as follow:

According to the Finkelstein-Schafer (FS) statistic [10], the cumulative distribution function (CDF) for each weather index x, which is a monotonic increasing function, is formulated by a function $CDF(x)$:

$$CDF(x) = \begin{cases} 0, & \text{for } x < x_1, \\ (i-0.5)/n, & \text{for } x_i \le x < x_{i+1}, \\ 1, & \text{for } x \ge x_n, \end{cases} \quad (1)$$

where n is the total number of elements; i is the rank order number (i = 1, 2, 3,…, n-1). From its definition, $CDF(x)$ is a monotonically increasing step function with steps of sizes $1/n$ occurring at x_i and is bounded by 0 and 1.

The FS statistic is calculated for each of the weather index by the following equation

$$FS_x(y,m) = \frac{1}{N}\sum_{i}^{N}\delta_i, \quad (2)$$

where δ_i is the absolute difference between the long-term CDF of the month and one year CDF for the same month at x_i (i = 1, 2, 3,…, n-1); N is the number of daily readings of the month (e.g. for January, N=31).

Considering the characteristics of solar energy systems, eight weather indices are considered in this paper. These indices are maximum, minimum and mean dry-bulb temperature (T_{max}, T_{min}, T_{ma}); minimum and mean relative humidity (RH_{min}, RH_{ma}); maximum and mean wind velocity (W_{max}, W_{ma}); and daily global solar radiation ($DGSR$). Only eight indices are used because some data (for instance, maximum relative humidity and minimum wind velocity) are not available in Northeast China.

The weighted sum (WS) of the FS statistic for the above eight weather indices is then calculated for each year. Moreover, the five years with the smallest WS values are chosen as the candidate years. The WS is defined and calculated as follows

$$WS(y,m) = \frac{1}{M}\sum_{x=1}^{M} WF_x \cdot FS_x(y,m), \quad (3)$$

where $WS(y,m)$ is the average weighted sum for the month m in the year y; WF_x is the weighting factor for the x^{th} weather index; M is the number of meteorological indices.

Various sets of the weighting factors were suggested in different references. The weighting factors in this paper, which are significant for forming TMY data, are shown in Table 2. A large weighting factor of 0.5 is assigned to the solar radiation because the criteria is mainly used for solar energy systems and the other weather variables (e.g. dry bulb temperature and relative humidity) are affected by solar radiation. For instance, in general, the higher for the solar radiation, the higher for the dry-bulb temperature.

Table 2. Weighting factors for FS statistics

T_{max}	T_{min}	T_{ma}	RH_{min}	RH_{ma}	W_{max}	W_{ma}	$DGSR$
1/24	1/24	3/24	1/24	2/24	2/24	2/24	12/24

The last step is to select the typical meteorological month (TMM) from the five candidate years. This paper applies a simper selection process introduced by Pissimanis [11]. The month with the minimum root mean square difference (RMSD) of global solar radiation is selected as the TMM. The RMSD is defined as follows

$$RMSD = \left[\frac{\sum_{i=1}^{N}(H_{y,m,i} - H_{ma})^2}{N}\right]^{1/2}, \quad (4)$$

where $H_{y,m,i}$ is the daily global solar radiation values of the year y, month m and day i; H_{ma} is mean values of the long-term global solar radiation for the month m; N is the number of daily readings of the month.

Results and discussion

Based on the above TMY method and the data of the eight stations listed in Table 1, the TMYs of the eight stations in three provinces of Northeast China are formed and analyzed in the following.

To illustrate the selection procedure, the Shenyang station in Liaoning province of Northeast China is chosen as an example. In addition, to reflect the seasonal changes, January and July are selected as the typical months for winter and summer, respectively.

For each calendar month, CDFs of each index between short term and the long term are compared and calculated by (1) and (2). With mean dry-bulb temperature and daily global solar radiation as example, the comparison between the short term CDFs and the long term CDFs for Shenyang station is given in Fig. 1 and 2. It is obvious that, in general, the short term CDFs appearing the typical "S" type distribution follow quite closely their long term counterparts. In Fig. 1, using the January of Shenyang as example, the CDF of mean dry-bulb temperature (Tma) for 2003 is most similar to the long term CDF (smallest value of FS statistic), while the CDF of Tma for 2000 is least similar (largest value of FS statistic). Also, the CDF of Tma for TMM of 2009 is between the two. Likewise, From Fig. 2, the CDFs of daily global solar radiation (DGSR) for January 1997 and July 2008 are closest to the long term CDF for January (in Fig. 2(a)) and for July (in Fig. 2(b)), while the DGSR CDFs for January 2008 (in Fig. 2(a)) and July 2000 (in Fig. 2(b)) are most dissimilar. It is also found that the years considered representative for a particular index might not be necessarily representative for another index at the same month. And similarly, the years considered typical for a certain month might not be inevitably typical for another month at the same weather index. For example, in Fig. 1(b), the CDF of Tma for July of 2005 follows the long term CDF remarkably well, whereas in Fig. 2(b), the CDF of DGSR for July of 2005 is not the best agreement with the long term CDF. Also, for instance, in Fig. 1(a), the CDF of Tma for January 2009 is compared the good with the long- term, whereas in Fig. 1(b), the CDF of Tma for July 2009 is the worst with respect to the long term CDF.

The FS statistic is estimated and examined for each weather index and for each month of every year in the database. Due to space limitation, only the FS values of daily global solar radiation for Shenyang station are shown in Table 3. It is found that the FS statistic (e.g. the FS statistic of DGSR in Table 3) often varies month to month and differs from one index to another.

Table 3. Summary of FS statistics of DGSR for Shenyang station

M	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	0.063	0.102	0.083	0.018	0.098	0.134	0.052	0.087	0.032	0.065	0.057	0.089	0.049	0.060	0.154	0.062
2	0.031	0.075	0.031	0.042	0.059	0.108	0.135	0.037	0.074	0.111	0.090	0.046	0.041	0.036	0.101	0.055
3	0.088	0.053	0.048	0.057	0.099	0.091	0.069	0.063	0.057	0.115	0.022	0.077	0.038	0.067	0.099	0.057
4	0.061	0.030	0.166	0.087	0.066	0.053	0.026	0.033	0.087	0.135	0.180	0.038	0.098	0.035	0.058	0.074
5	0.051	0.049	0.146	0.042	0.039	0.093	0.026	0.025	0.150	0.222	0.140	0.042	0.038	0.046	0.098	0.087
6	0.036	0.037	0.068	0.094	0.049	0.086	0.121	0.147	0.044	0.090	0.155	0.109	0.055	0.115	0.039	0.055
7	0.060	0.100	0.084	0.124	0.098	0.073	0.138	0.033	0.074	0.085	0.078	0.052	0.051	0.043	0.030	0.068
8	0.079	0.224	0.029	0.041	0.052	0.043	0.050	0.079	0.055	0.116	0.043	0.059	0.030	0.046	0.067	0.148
9	0.039	0.050	0.044	0.051	0.058	0.063	0.023	0.107	0.063	0.080	0.046	0.037	0.056	0.047	0.078	0.032
10	0.076	0.087	0.033	0.070	0.040	0.055	0.035	0.032	0.123	0.034	0.073	0.055	0.029	0.025	0.076	0.062
11	0.065	0.075	0.029	0.041	0.039	0.048	0.025	0.087	0.055	0.108	0.153	0.073	0.062	0.035	0.139	0.030
12	0.128	0.077	0.056	0.023	0.107	0.071	0.086	0.060	0.092	0.042	0.163	0.128	0.042	0.046	0.047	0.025

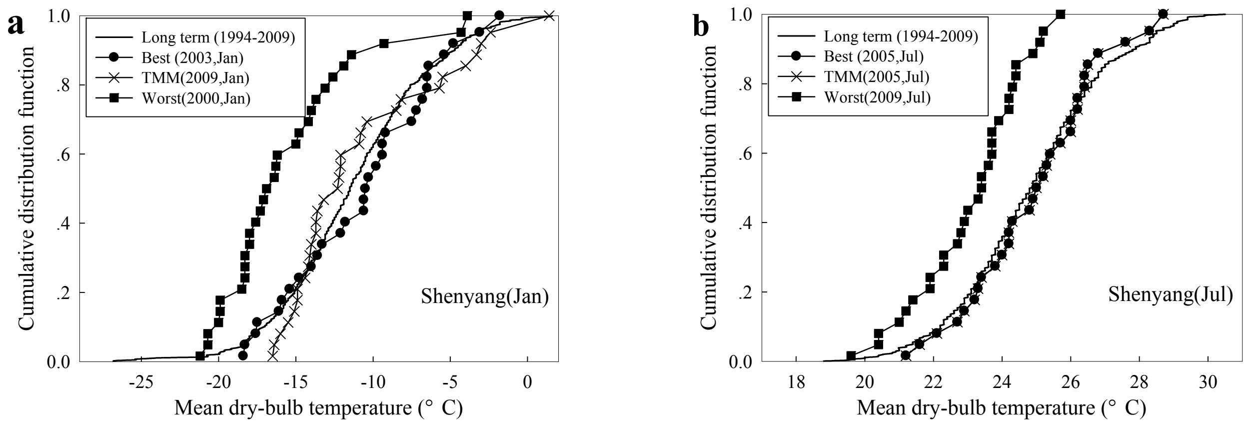

Fig. 1. Comparison of individual monthly CDF with long term CDF (T_{ma}) in January (a) and July (b) for Shenyang station

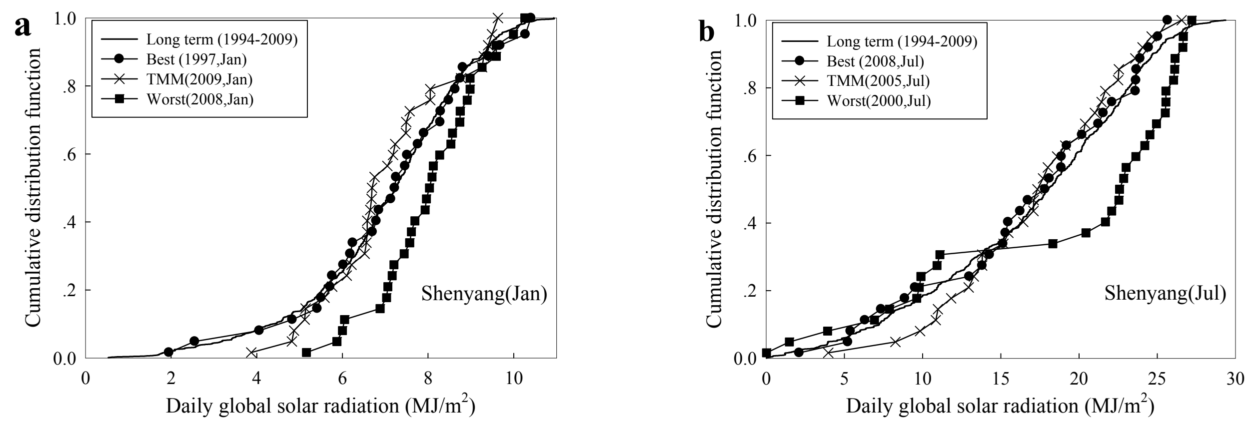

Fig .2. Comparison of individual monthly CDF with long term CDF (*DGSR*) in January (a) and July (b) for Shenyang station

From (3), the weighted sum (WS) of the FS statistics is computed and determined. The values of WS for Shenyang station and the five candidate years of each calendar month (bold numbers) are tabulated and presented in Table 4.

The RMSD values of daily global solar radiation are solved by the above (4). The RMSD results of Shenyang station and the minimum value of RMSD for each month (bold characters) are shown in Table 5. The smallest RMSD values for each month vary between 1.3528 and 6.5429 MJ/m2.

Then, the month with smallest RMSD is selected as the TMM. Finally, the 12 TMMs is used to form a TMY. The TMY for Shenyang station can be found in Table 6.

These database would be useful for the utilization of solar energy system in Northeast China.

Table 6 shows a summary of the TMYs selected for eight stations in three provinces of Northeast China. In order to know which years tend to follow the 16 year (1994-2009) long term weather patterns more closely than the others, the TMYs acquired for the eight stations in Northeast China are analyzed and investigated. Fig. 3 shows the year selection frequency for the TMYs derived from the 1994-2009 database. It can be found that 2004 and 2007 are the most and least frequent years respectively. In Fig. 3, the frequency occurrence of the 2004 year is up to12.5%. This means the typical data derived from 2004 is the prime eement with the long term (1994-2009) data.

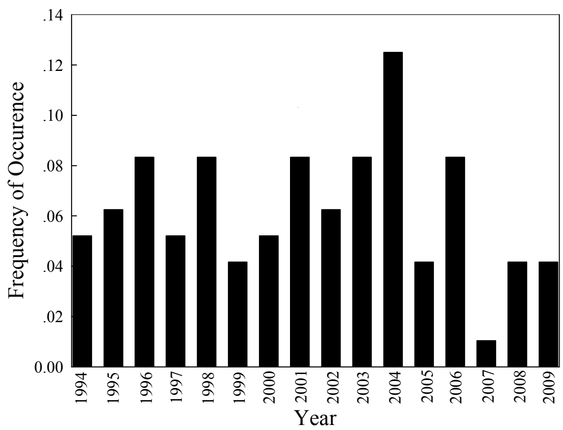

Fig. 3. Summary of year selection frequency for 1994-2009 TMY

Table 4. Summary of WS of FS statistic for Shenyang station (bold numbers correspond to the five candidate years of each month)

M	1994	1995	1996	1997	1998	1999	2000	2001
1	**0.0107**	0.0174	0.0114	**0.0074**	0.0125	0.0197	0.0162	0.0163
2	**0.0080**	0.0110	**0.0091**	**0.0080**	0.0126	0.0131	0.0199	0.0115
3	0.0106	**0.0077**	0.0103	**0.0083**	0.0148	0.0130	**0.0075**	**0.0084**
4	0.0101	**0.0081**	0.0156	0.0090	0.0127	**0.0072**	**0.0052**	**0.0075**
5	0.0103	0.0115	0.0149	**0.0086**	**0.0066**	0.0107	**0.0053**	**0.0067**
6	**0.0078**	**0.0084**	**0.0088**	0.0131	0.0099	0.0102	0.0175	0.0173
7	0.0144	0.0155	0.0142	0.0187	**0.0103**	0.0133	0.0207	0.0117
8	0.0123	0.0200	0.0089	0.0104	0.0086	**0.0080**	0.0106	0.0090
9	**0.0086**	**0.0078**	**0.0080**	0.0104	0.0101	0.0101	**0.0064**	0.0112
10	0.0088	0.0103	0.0082	0.0119	0.0084	0.0098	**0.0079**	**0.0078**
11	0.0094	0.0116	**0.0058**	**0.0072**	0.0078	0.0084	**0.0062**	0.0097
December	0.0114	0.0107	0.0132	0.0102	0.0121	**0.0086**	0.0094	0.0110
M	2002	2003	2004	2005	2006	2007	2008	2009
1	0.0109	**0.0071**	0.0115	**0.0105**	0.0110	0.0144	0.0172	**0.0093**
2	0.0172	0.0126	0.0143	0.0144	**0.0103**	0.0112	0.0155	**0.0096**
3	0.0138	0.0125	0.0093	0.0100	**0.0060**	0.0103	0.0153	0.0096
4	0.0092	0.0129	0.0188	**0.0057**	0.0138	0.0090	0.0095	0.0106
5	0.0194	0.0193	0.0139	0.0092	**0.0058**	0.0093	0.0161	0.0129
6	**0.0092**	0.0105	0.0171	0.0128	**0.0097**	0.0166	0.0145	0.0128
7	**0.0106**	0.0115	0.0106	**0.0070**	**0.0077**	0.0111	**0.0104**	0.0151
8	**0.0083**	0.0138	0.0085	**0.0070**	**0.0067**	**0.0079**	0.0111	0.0154
9	0.0124	**0.0086**	0.0086	0.0088	0.0102	0.0108	0.0109	0.0089
10	0.0129	**0.0048**	0.0118	**0.0075**	**0.0053**	0.0096	0.0109	0.0104
11	0.0120	0.0098	0.0161	0.0127	**0.0066**	**0.0075**	0.0128	0.0099
12	0.0107	**0.0066**	0.0157	0.0201	**0.0065**	0.0119	**0.0083**	**0.0083**

Table 5. RMSD (MJ/m^2) of DGSR for the five candidate years at Shenyang station (bold numbers correspond to the min value in the month)

year	January	1994	1997	2003	2005	**2009**	July	1998	2002	**2005**	2006	2008
RMSD		1.9061	1.9737	1.8982	1.8298	**1.4779**		7.0274	5.7967	**5.2308**	5.6133	6.5459
year	February	1994	1996	**1997**	2006	2009	August	1999	**2002**	2005	2006	2007
RMSD		2.9039	2.8918	**2.7319**	3.7731	3.2397		6.3501	**5.3472**	6.3209	6.5659	6.6722
year	March	1995	**1997**	2000	2001	2006	September	**1994**	1995	1996	2000	2003
RMSD		4.6122	**3.6407**	4.9080	4.7633	4.7120		**4.1717**	4.6976	5.0640	5.1818	6.1704
year	April	**1995**	1999	2000	2001	2005	October	2000	**2001**	2003	2005	2006
RMSD		**5.7412**	6.7960	5.9783	5.7499	6.0400		4.3431	**3.6942**	4.7471	4.2195	3.9475
year	May	1997	1998	2000	2001	**2006**	November	1996	1997	2000	**2006**	2007
RMSD		7.2136	7.6182	6.4018	6.5230	**6.0313**		2.8450	2.7861	2.9053	**2.7438**	3.1269
year	June	1994	1995	**1996**	2002	2006	December	**1999**	2003	2006	2008	2009
RMSD		7.0481	7.6254	**6.5429**	7.9038	7.0655		**1.3528**	1.5334	1.8407	1.6079	2.0264

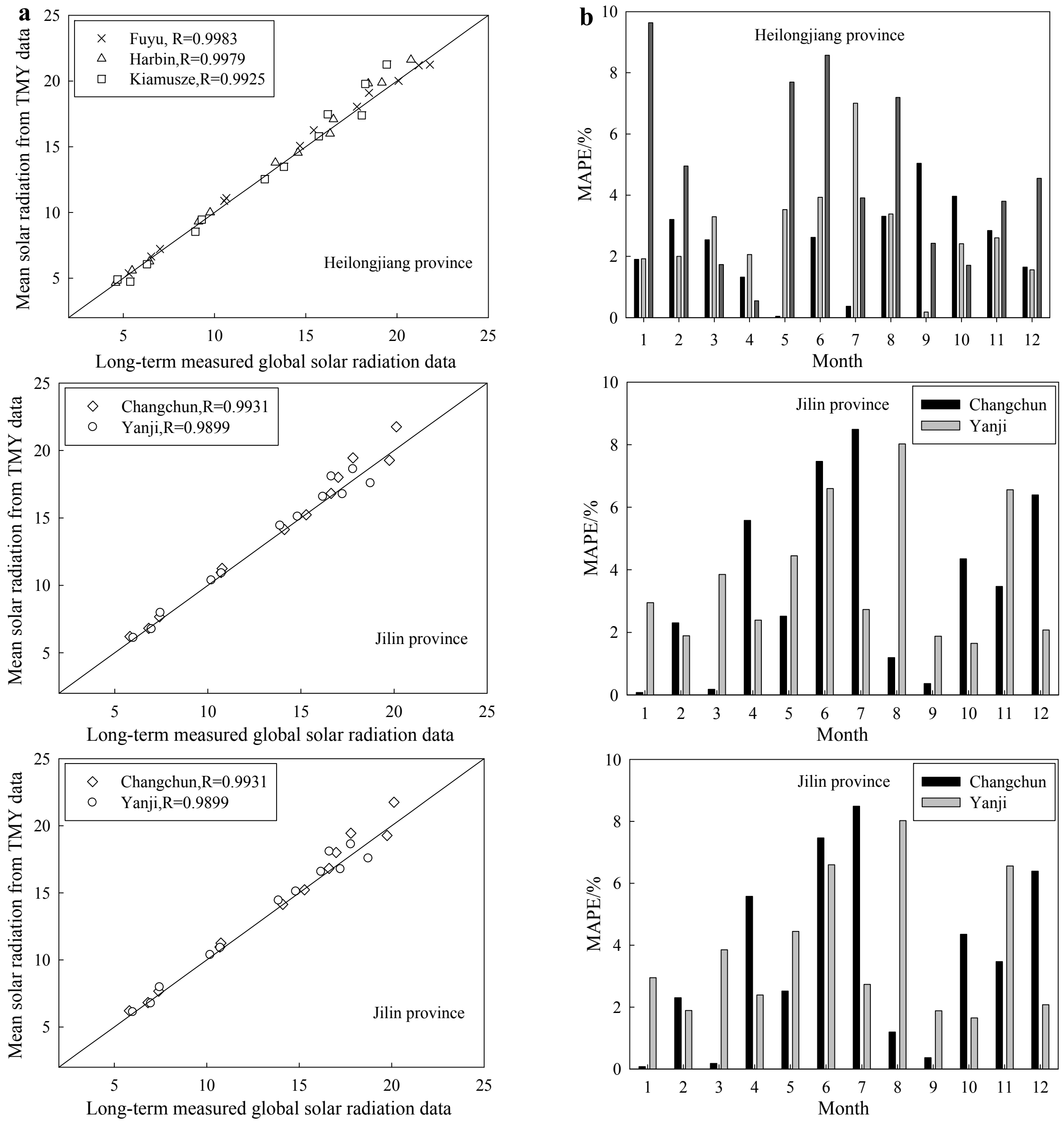

Fig. 4. Comparison of monthly mean values of long term solar radiation data and solar radiation from TMY data (Units: MJ/m2) (a), and the corresponding MAPE (b) for each month and for eight stations in Northeast China

Additionally, the accuracy of TMY data is excellent on monthly bases. The monthly average values of the long term measured data and typical solar radiation derived from the TMY data for the eight cities in three provinces Heilongjiang, Jilin, Liaoning) of Northeast China are compared and shown in Fig. 4(a).

Table 6. Summary of the TMYs selected for eight stations in three provinces of Northeast China

Province	Location	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heilongjiang	Fuyu	2003	1994	2004	1994	1994	2003	1996	2001	2008	2001	2008	2002
	Harbin	2003	1998	2004	1996	2001	1995	1998	2009	2004	2004	2009	1996
	Kiamusze	2003	1997	1997	2008	2002	1995	2000	1995	2002	2008	2000	2003
Jilin	Changchun	2004	1997	2006	2001	1996	2001	2002	2008	2009	2006	2006	1996
	Yanji	2005	1999	2004	2001	2006	2003	2005	2001	2006	1998	2006	2006
Liaoning	Chaoyang	1998	1999	1996	2007	1999	1995	2002	2006	2004	2003	1994	1998
	Dalian	2004	1995	2000	2000	1996	2009	2004	2000	1998	1998	2004	1998
	Shenyang	2009	1997	1997	1995	2006	1996	2005	2002	1994	2001	2006	1999

As can be seen from Fig. 4(a), the degree of the deviation from the diagonal between the TMY data and the recorded data is small. To be obvious, the corresponding mean absolute percentage error (MAPE) between monthly mean values of the long term measured data and typical solar radiation data from TMY data for each month and for eight stations are shown in Fig. 4(b). From Fig. 4(a) and (b), the TMY data generally represent good agreement with the long-term data. In particular, the TMY data for Fuyu station is the best. The R value in the Fuyu station is up to 0.9983, and the MAPE lies between 0.03% and 5.04%.

Conclusions

The generation of the TMY data are essential and important for solar energy utilization. In this paper, the TMY method using the Finkelstein-Schafer statistical and novel assigned weighting factors is applied and utilized. Typical meteorological years for eight stations located in three provinces of Northeast China are formed based on the recent and accurate 16 years (1994-2009) recorded weather data. It is found that the cumulative distribution functions of each weather index for the TMMs selected tend to follow their long term counterparts well. It is also seen that the typical data from the 2004 is the prime agreement with the long-term data. In addition, comparison analysis between the monthly data from TMYs and the long term recorded data for this region show that TMYs perform well on monthly bases.

From the analysis and results, it is concluded that the solar energy resource in the three provinces of Northeast China is abundant and potential. It is believed that the TMY data developed by this paper will exert positive effects on some energy-related scientific researches and engineering applications in Northeast China. Future researches will focus on the TMY data on a larger regional scale.

Acknowledgements

The research is financially supported by National High Technology Research and Development Program of China (863 Program) (No. 2012AA050214), NSFC (No. 50907010), Natural Science Foundation of Jiangsu Province (No. BK2012753) and Major Scientific Research Guidance Foundation of Southeast University (3216002103). The authors would like to thank China Meteorological administration.

References

1. **Chow T. T., Chan A. L. S., Fong K. F., Lin Z.** Some perceptions on typical weather year—from the observations of Hong Kong and Macau // Solar Energy, 2006. – No. 80(4). – P. 459–467.
2. **Hall I. J., Prairie R. R., Anderson H. E., Boes E. C.** Generation of a typical meteorological year // Proceeding of the 1978 annual meeting of the American Society of the international solar energy society, 1978. – P. 641–645.
3. **Said S. A. M., Kadry H. M.**. Generation of representative weather–year data for Saudi Arabia // Applied Energy, 1994.–No. 48(2). – P. 131–136.
4. **Kalogirou S. A.**. Generation of typical meteorological year (TMY–2) for Nicosia, Cyprus // Renewable Energy, 2003.– No. 28(15). – P. 2317–2334.
5. **Marion W., Urban K.** User manual for TMY2s–Typical Meteorological Years Derived from the 1961–1990 National Solar Radiation Data Base. – National Renewable Energy Laboratory, 1995.
6. **Wilcox S., Marion W.** Users Manual for TMY3 Data Sets. – National Renewable Energy Laboratory, 2008. DOI: 10.2172/928611.
7. **Petrakis M., Kambezidis H. D., Lykoudis S., Adamopoulos A. D., Kassomenos P., Michaelides I. M., Kalogirou S. A., Roditis G., Chrysis I., Hadjigianni A.** Generation of a "typical meteorological year" for Nicosia, Cyprus // Renewable Energy, 1998. – No. 13(3). – P. 381–388.
8. **Zhou J., Wu Y. Z., Yan G.** Generation of typical solar radiation year for China // Renewable Energy, 2006. – No. 31(12). – P. 1972–1985.
9. **Jiang Y. N.**. Generation of typical meteorological year for different climates of China // Energy, 2010. – No. 35(5). – P. 1946–1953.
10. **Finkelstein J. M., Schafer R. E.**. Improved goodness–of–fit tests // Biometrika, 1971. – No. 58(3). – P. 641–645.
11. **Pissimanis D., Karras G., Notaridou V., Gavra K.**. The generation of a "typical meteorological year" for the city of Athens // Solar Energy, 1988. – No. 40(5). – P. 405–411.

Received 2011 11 08
Accepted after revision 2012 01 22

Qingshan Xu, Haixiang Zang. Development of TMY database in Northeast China for Solar Energy Applications // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 7(123). – P. 103–108.

In this study, typical meteorological years (TMYs) of eight cities in three provinces of Northeast China are generated by the recorded weather data (dry-bulb temperature, relative humidity, wind velocity and global solar radiation) in the period of 1994-2009, using Finkelstein-Schafer (FS) statistical method. The cumulative distribution function (CDF) for each weather index and for each year is compared with the CDF for the long-term years. The TMY database are essential in the applications of solar energy systems. Moreover, such database can also be applied in many engineering applications such as meteorology and building simulations. Ill. 4, bibl. 11, tabl. 6 (in English; abstracts in English and Lithuanian).

Qingshan Xu, Haixiang Zang. TMM duomenų bazės šiaurės Kinijoje sukūrimas saulės energijos programoms // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 7(123). – P. 103–108.

Naudojant 1994–2009 metų sinoptinius duomenis Finkelsteino ir Schaferio statistiniu metodu sugeneruoti tipiniai meteorologinai metai (TMM) aštuoniems trijų šiaurės Kinijos provincijų miestams. Kumulitatyvinė pasiskirstymo funkcija (KPS) kiekvienų metų kiekvieno sinoptinio parametro palyginta su ilgesnio periodo KPS. Saulės energijos sistemose TMM duomenų bazė yra esminis dalykas. Be to, tokia duomenų bazė gali būti pritaikoma daugelyje inžinerinių programų, tokių kaip meteorologijos ir statybų modeliavimas. Il. 4, bibl. 11, lent. 6 (anglų kalba; santraukos anglų ir lietuvių k.).