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GENERATION OF TYPICAL SOLAR RADIATION YEAR FOR MEDITERRANEAN REGION OF TURKEY

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Typical solar radiation data is very important for the calculations concerning many solar applications. In this study, typical solar radiation years for six provinces located in the Mediterranean region of Turkey are generated from the daily global solar radiation data measured at least for 14 years, using the Finkelstein-Schafer statistical method. The typical daily global solar radiation data for the locations considered is presented throughout a year in a tabular form. The data obtained is also analyzed. It is expected that the typical data presented for the Mediterranean region, which is rich for solar energy potential in Turkey, will be useful to the designers of solar energy systems.

Keywords: *Mediterranean region; Solar radiation; Test reference year; Turkey*

INTRODUCTION

Solar radiation data is a critical parameter for the prediction of long-term performance of solar energy systems. It is also a key input in modeling and designing of solar energy applications. Therefore, reliable solar radiation data should be readily available for particular settlement locations.

The need for one-year appropriate meteorological data led to the development of methodologies known as the Typical Meteorological Year (TMY) or Test Reference Year (TRY) (Argiriou et al. 1999). TMY or TRY is a representative data that consists of the month selected from the individual years and concatenated to form a complete year. The intended use is for computer simulations of solar energy conversion systems and building systems. A TMY is not necessarily a good indicator of conditions over the next year or even the next five years. Rather, it represents conditions judged to be typical over a long period of time (Marion and Urban 1995). Typical weather year data sets can be generated for several climatic variables or only for solar radiation. Many attempts have been made to generate such weather databases for different areas around the world (Argiriou et al. 1999; Bulut 2003; Bulut 2004; Fagbenle 1995; Lam et al. 1996; Miguel and Bilbao 2005; Petrakis et al. 1998; Said and Kadry 1994; Shaltout and Tadros 1994).

The main aim of this study is to generate representative solar radiation data for six provinces located in the Mediterranean region of Turkey.

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DATA AND LOCATIONS

The daily global solar radiations recorded during the period 1981–2001 are used for producing the typical solar radiation data. In Turkey, meteorological measurements are taken and the related records are kept by the Turkish State Meteorological Service (Turkish abbreviation ''DMİ''). Meteorological stations are located in city centers, and there is generally only one station in each city. In this study, the global solar radiation data were taken from the Turkish State Meteorological Service in computer diskettes for each location. There were missing and invalid measurements in the data, and they were marked and coded as 99999 in the files. The missing and invalid measurements, accounting for approximately 0.36% of the whole database, were replaced with the values of preceding or subsequent days by interpolation. In the calculations, the year was excluded from the database if more than 15 days-measurements were not available in a month. Table 1 provides geographical information for locations and the periods of the data considered. The location of the Mediterranean region with its provinces is shown on the map of Turkey in Figure 1. Provinces in the region are Adana, Antakya, Antalya, Burdur, Isparta, Kahramanmaras, Kilis, Mersin, and Osmaniye. Burdur, Kilis, and Osmaniye are excluded in this study because of lack of solar radiation data.

Table 1 Geographical and solar radiation database information of the provinces located in the Mediterranean region of Turkey.

Province	Longitude (° ″E)	Latitude (° ″N)	Elevation (m)	Daily global solar radiation data	
				Period	Total years
Adana	35 18	36 59	20	1986—2001	16
Antakya	36 07	36 15	100	1984—1998	14
Antalya	30 42	36 53	42	1983—2001	19
Isparta	30 33	37 45	997	1981—1998	18
K.Maraş	36 56	37 36	549	1985—2001	17
Mersin	34 36	36 49	5	1984—1998	15

Figure 1 Mediterranean Region of Turkey.

The Mediterranean region takes its name from the Mediterranean Sea and occupies 15% of the total area of Turkey with its 120,000 square kilometers of land. West and Mid-Taurus mountains run parallel to the coastline. Due to high and steep mountains, the valleys between the sea and mountain range are very narrow. The population is concentrated especially at the locations suitable for agriculture, tourism, industry, and commerce (Sansal 2008).

METHODOLOGY

A nonparametric method, known as Finkelstein-Schafer (FS) statistics (Finkelstein and Schafer 1971), is the common methodology for generating typical weather data (Argiriou et al. 1999; Bulut 2003; Bulut 2004; Fagbenle 1995; Marion and Urban 1995; Petrakis et al. 1998; Said and Kadry 1994; Shaltout and Tadros 1994). In the present study, FS methodology is used for the generation of typical solar radiation year. According to FS statistics (Finkelstein and Schafer 1971), if a number, n, of observations of a variable X are available and have been sorted into an increasing order X_1, X_2,...,X_n, the cumulative frequency distribution function (CDF) of this variable is given by a function $S_n(X)$, which is defined as follows:

$$S_n(X) = \begin{cases} 0 & \text{for } X < X_1 \\ (k - 0.5)/n & \text{for } X_k < X < X_{k+1} \\ 1 & \text{for } X > X_n \end{cases} \quad (1)$$

where k is rank order number. The FS by which comparison between the long-term CDF of each month and the CDF for each individual year of the month was done is given by the equation

$$FS = (1/n) \sum_{i=1}^{n} \delta_i \quad (2)$$

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,...,n), n being the number of daily readings of the month.

δ_i and $F(X_i)$ are expressed with the following equations:

$$\delta_i = \max[|F(X_i) - (i-1)/n|, |F(X_i) - i/n|] \quad (3)$$

$$F(X_i) = 1 - \exp(-X_i/\bar{X}) \quad (4)$$

where X_i is an order sample value in a set of n observations sorted in an increasing order and $\bar{X}$ is the sample average.

Finally, the representative year for each month of the data set was determined on the basis that the representative year is that of the smallest value of FS, i.e.

$$TRY = \min(FS) \equiv \min(\delta_i) \quad (5)$$

Table 2 Test Reference Years with minimum (min) FS and monthly mean of the daily global solar radiation ($\mathbf{I_{TRY}}$) for the Mediterranean region of Turkey.

Province	Month	Year	Min FS	I_{TRY} (MJ/m^2day)	Province	Month	Year	Min FS	I_{TRY} (MJ/m^2day)
Adana	Jan.	1992	0.033	8.31	Isparta	Jan.	1993	0.029	6.94
	Feb.	2000	0.034	11.08		Feb.	1993	0.029	9.81
	Mar.	1993	0.039	15.01		Mar.	1983	0.037	13.16
	Apr.	1994	0.052	17.98		Apr.	1996	0.029	15.28
	May	1991	0.040	21.59		May	1995	0.038	18.00
	June	1991	0.041	23.57		June	1990	0.028	19.59
	July	1994	0.047	22.93		July	1982	0.030	19.46
	Aug.	1999	0.041	21.02		Aug.	1984	0.032	17.62
	Sep.	1989	0.053	17.15		Sep.	1983	0.030	15.12
	Oct.	1989	0.051	12.78		Oct.	1998	0.040	11.36
	Nov.	1996	0.051	8.78		Nov.	1997	0.029	7.49
	Dec.	1992	0.045	6.65		Dec.	1993	0.045	5.97
Antakya	Jan.	1984	0.063	6.00	K. Maraş	Jan.	1997	0.049	7.47
	Feb.	1997	0.064	8.71		Feb.	1987	0.052	10.13
	Mar.	1994	0.057	13.08		Mar.	1992	0.053	15.26
	Apr.	1987	0.058	17.18		Apr.	1985	0.047	19.66
	May	1986	0.066	19.41		May	1995	0.051	23.72
	June	1986	0.066	22.78		June	1999	0.047	25.87
	July	1988	0.067	22.50		July	1990	0.055	26.79
	Aug.	1989	0.067	19.93		Aug.	1993	0.052	23.64
	Sep.	1989	0.068	16.16		Sep.	1992	0.055	19.80
	Oct.	1990	0.069	11.43		Oct.	1990	0.051	13.83
	Nov.	1993	0.066	7.35		Nov.	1997	0.042	8.31
	Dec.	1995	0.039	5.88		Dec.	1986	0.038	6.31

Antalya	Jan.	1988	0.032	9.70	Mersin	Jan.	1998	0.040	9.03
	Feb.	1993	0.040	12.78		Feb.	1984	0.050	12.60
	Mar.	1991	0.045	17.08		Mar.	1993	0.046	17.15
	Apr.	1991	0.039	21.26		Apr.	1994	0.040	20.59
	May	2000	0.041	24.47		May	1997	0.044	23.48
	June	1994	0.042	27.30		June	1984	0.035	24.83
	July	1988	0.045	26.28		July	1996	0.037	24.84
	Aug.	1995	0.048	23.56		Aug.	1987	0.037	22.97
	Sep.	1993	0.039	20.93		Sep.	1992	0.033	19.65
	Oct.	1998	0.040	15.17		Oct.	1984	0.040	14.93
	Nov.	1990	0.032	10.45		Nov.	1993	0.053	10.41
	Dec.	1989	0.029	8.27		Dec.	1990	0.049	8.01

Table 3 Daily global solar radiation values obtained from Test Reference Year data for Adana.

	Global Solar Radiation on a Horizontal Surface (MJ/m^2day)											
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	7.71	8.33	14.65	19.39	16.56	23.53	26.02	22.52	19.43	13.77	9.98	1.84
2	9.64	12.75	12.17	17.70	24.19	23.56	25.37	20.97	19.10	11.00	11.10	2.67
3	8.75	11.13	15.83	16.55	25.97	24.94	23.47	20.51	19.14	14.04	12.11	9.03
4	8.27	10.05	14.72	21.27	26.65	24.41	23.68	20.49	19.33	13.10	11.86	7.86
5	2.65	3.16	14.93	19.99	21.28	19.97	25.52	20.67	18.09	12.72	6.57	8.45
6	8.12	14.14	4.88	15.82	23.53	23.74	25.24	21.44	17.91	10.34	10.66	4.02
7	8.54	14.15	3.97	12.03	24.24	25.10	25.62	23.37	17.19	10.91	11.34	2.14
8	8.69	14.54	5.13	17.72	9.11	21.67	24.83	23.31	17.30	14.94	10.21	3.29
9	9.34	13.04	4.37	19.99	25.97	22.97	25.24	20.80	19.31	15.98	10.34	8.69
10	9.50	14.22	15.30	19.89	25.57	22.81	23.70	19.84	17.68	16.33	10.54	6.96
11	7.42	14.55	17.50	22.37	20.83	25.78	21.22	20.65	17.59	15.50	10.76	8.38
12	3.47	11.25	17.52	21.06	23.68	25.58	21.37	22.97	18.15	14.45	10.76	6.08
13	6.00	14.65	16.09	19.84	14.81	24.26	23.11	23.46	12.34	14.48	11.11	7.53
14	6.18	13.79	16.69	21.18	18.27	23.24	18.02	22.68	18.99	15.75	10.72	0.54
15	7.74	2.15	15.37	21.83	12.36	23.90	17.61	19.63	17.41	14.99	10.42	1.75
16	9.33	3.28	18.45	12.96	21.20	25.64	20.76	18.64	16.25	12.67	10.21	1.29
17	8.96	13.01	17.82	15.72	24.17	25.47	20.50	19.16	17.41	6.40	9.34	7.67
18	7.91	6.42	12.86	19.04	26.08	24.92	20.12	19.94	19.79	9.51	8.69	8.62
19	7.99	6.37	15.18	16.13	25.92	25.22	22.67	22.42	18.15	10.98	7.20	8.64
20	4.88	16.30	9.80	14.28	25.72	24.76	25.76	18.79	18.75	14.92	3.66	9.59
21	9.75	2.31	19.84	18.20	23.12	23.06	24.64	17.12	18.95	14.74	8.23	9.30
22	11.25	3.68	17.75	15.27	25.94	23.14	24.68	17.61	17.04	14.03	4.72	7.74
23	10.87	14.64	19.15	19.26	25.25	23.75	24.48	14.91	15.97	14.22	4.61	7.52
24	10.24	5.07	19.46	13.96	23.67	24.90	24.49	18.38	16.42	13.69	8.58	8.54
25	10.87	15.08	18.69	13.83	14.23	22.58	22.98	19.72	15.70	12.77	8.22	8.56
26	11.3	15.05	19.22	20.78	25.20	23.11	21.99	23.09	15.99	10.81	5.95	9.29
27	11.35	17.97	18.31	21.55	20.11	20.00	23.95	24.01	13.12	10.93	7.17	9.21
28	11.01	19.15	16.48	22.32	21.71	20.63	22.22	24.21	15.20	10.86	4.89	7.86
29	7.71	–	19.10	6.39	14.01	23.13	20.39	23.72	13.01	7.59	6.18	8.92
30	9.51	–	19.36	23.08	17.99	21.22	21.87	23.68	13.67	11.97	7.41	9.57
31	2.64	–	14.79	–	21.95	–	19.29	23.01	–	11.81	–	4.75

Table 4 Daily global solar radiation values obtained from Test Reference Year data for Antalya.

	Global Solar Radiation on a Horizontal Surface (MJ/m^{2}day)											
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	10.32	14.98	13.11	14.97	26.06	26.52	26.63	26.02	21.61	19.50	13.99	12.96
2	1.11	15.07	18.36	7.46	19.62	28.04	26.95	23.98	20.51	19.13	9.73	12.19
3	0.41	13.93	12.90	22.79	17.53	29.08	27.28	23.21	23.63	18.18	12.27	12.27
4	6.20	15.04	16.56	14.39	14.39	27.78	27.91	24.24	22.60	13.88	12.8	12.21
5	10.56	15.05	22.40	22.59	10.80	24.50	26.60	23.61	22.41	18.44	12.19	11.65
6	11.58	15.01	22.19	20.73	18.97	17.05	30.69	23.34	20.80	16.94	6.18	9.97
7	12.24	10.95	21.01	4.55	16.90	24.34	26.90	24.01	24.39	17.33	11.48	11.28
8	10.83	16.16	19.48	23.31	29.04	29.86	29.86	25.35	23.43	17.31	7.06	4.48
9	8.09	16.03	18.70	20.13	29.99	29.05	28.66	25.32	23.41	18.67	13.13	3.47
10	10.64	14.28	3.37	22.65	29.92	29.21	26.53	25.49	23.19	18.61	9.75	5.43
11	3.63	15.31	8.74	24.96	29.49	29.59	28.48	25.16	22.14	17.86	14.06	4.65
12	10.86	17.03	5.51	25.72	26.17	28.36	27.23	25.57	21.60	15.61	14.33	11.63
13	12.77	17.68	14.74	15.71	27.55	28.27	27.05	25.64	20.19	13.16	13.26	9.42
14	9.48	16.59	22.23	21.83	25.22	26.77	26.90	25.47	20.46	15.88	12.57	10.84
15	12.43	14.97	21.3	15.06	21.93	16.01	27.90	24.49	19.08	15.91	11.64	10.32
16	13.88	11.26	5.80	27.06	15.92	29.02	28.43	22.55	20.61	16.13	11.80	9.59
17	13.15	3.20	6.21	26.37	15.95	29.20	27.02	22.45	19.52	16.49	13.02	9.87
18	12.87	14.46	8.90	22.60	28.08	28.86	26.04	24.16	20.50	15.50	12.24	4.51
19	12.20	2.57	21.52	20.31	29.54	28.06	22.85	22.57	19.46	15.39	5.30	10.44
20	7.80	7.06	18.62	25.28	26.40	29.20	24.07	22.59	19.29	15.77	3.57	10.18
21	13.09	9.13	20.75	24.62	28.54	28.53	23.52	21.45	20.98	15.48	11.64	10.84
22	12.15	7.11	20.21	23.98	27.21	27.87	24.86	19.90	22.14	15.03	11.21	10.16
23	1.66	12.15	23.60	24.28	27.60	20.86	26.27	19.90	21.66	14.65	10.83	10.36
24	2.24	3.57	23.12	24.38	22.00	27.20	27.49	23.72	20.85	13.95	7.67	0.78
25	12.34	13.93	23.56	23.99	30.92	29.40	27.04	23.56	20.63	11.75	10.32	7.21
26	12.78	11.65	23.24	27.60	27.43	29.52	27.35	23.31	20.78	6.81	10.30	3.81
27	10.22	18.18	21.65	28.76	30.16	29.93	26.31	21.88	19.80	8.54	10.98	2.78
28	12.72	15.38	12.56	22.84	29.51	28.98	21.99	22.98	19.15	11.99	8.93	4.27
29	13.14	–	20.11	18.18	25.05	29.56	18.46	22.93	17.00	15.51	8.74	3.52
30	8.97	–	23.99	20.67	20.70	28.33	22.86	22.35	16.00	13.81	2.49	3.84
31	10.42	–	14.94	–	30.11	–	24.48	23.20	–	6.98	–	11.58

Table 5 Daily global solar radiation values obtained from Test Reference Year data for Mersin.

	Global Solar Radiation on a Horizontal Surface (MJ/m^{2}day)											
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	11.40	10.70	17.03	23.44	25.05	18.41	26.34	22.70	22.76	18.87	6.78	9.35
2	11.28	10.66	14.28	23.93	13.74	18.63	27.32	23.15	22.59	16.05	13.83	3.87
3	9.56	8.37	17.83	24.42	24.52	20.05	27.12	23.87	22.24	16.29	13.49	4.27
4	3.16	11.89	16.16	24.57	25.67	24.69	27.53	24.01	21.39	16.51	12.52	5.27
5	12.24	12.08	18.24	20.60	26.99	26.68	25.57	23.81	20.91	18.15	13.54	2.34
6	10.30	7.28	6.42	19.67	26.45	26.67	19.66	24.36	20.65	17.25	13.10	10.00
7	8.46	7.03	6.40	18.78	27.50	26.30	23.84	22.95	19.92	15.11	12.46	11.05
8	9.85	8.89	9.23	21.13	26.08	26.32	26.19	22.03	19.16	16.93	9.98	7.15
9	11.43	5.53	4.09	24.01	26.80	25.27	22.76	23.11	21.45	17.09	9.84	10.15
10	4.36	11.65	18.67	22.98	25.34	25.62	23.96	23.45	22.34	16.87	11.68	10.36
11	8.59	13.16	18.17	24.24	26.66	25.89	18.09	23.99	21.07	15.03	10.88	10.86
12	11.81	9.28	19.89	24.37	25.90	27.00	24.05	24.84	21.37	15.89	12.97	9.12
13	11.40	10.98	19.33	24.43	21.89	26.22	25.17	23.24	20.63	15.95	13.55	5.04
14	11.05	13.69	18.41	21.00	25.14	24.76	22.87	20.90	20.33	14.18	3.83	7.07
15	10.85	12.46	18.94	24.40	22.74	27.25	24.47	23.57	19.84	13.92	13.37	7.31
16	11.19	14.22	20.40	13.83	18.69	27.63	23.89	24.05	19.68	11.52	10.90	3.62
17	10.00	14.71	19.84	15.67	14.05	26.66	20.37	20.58	19.67	12.48	1.46	10.11
18	11.17	15.44	14.30	21.73	17.24	26.52	24.98	23.99	19.85	15.60	10.35	10.20
19	10.28	15.31	19.78	16.75	19.24	25.94	24.38	24.70	18.75	15.86	11.44	9.48
20	2.58	15.41	14.44	14.96	22.86	24.92	25.88	24.06	17.31	15.81	10.21	5.02
21	2.68	14.66	21.58	20.27	20.38	26.76	24.61	23.33	15.96	16.32	8.72	5.33
22	7.03	16.77	20.73	16.56	24.17	27.25	25.26	21.70	17.69	15.26	10.27	7.41
23	6.25	15.69	21.45	25.40	21.45	26.22	23.54	21.53	12.46	14.87	11.26	10.66
24	2.01	15.94	21.05	19.09	23.24	24.52	25.42	21.93	16.4	15.08	7.42	7.10
25	6.99	15.04	21.70	25.00	23.59	25.10	27.09	21.24	18.98	14.52	10.13	10.9
26	12.75	16.59	20.99	24.41	25.04	24.06	26.42	22.96	16.00	13.42	8.52	10.68
27	7.88	17.31	19.57	24.68	26.33	21.62	26.48	23.36	20.17	13.56	11.41	10.40
28	9.83	12.17	17.46	27.54	25.02	20.92	26.65	22.95	19.49	5.88	11.49	5.45
29	5.52	–	19.55	27.0	25.02	22.98	27.89	23.03	20.52	12.61	10.76	10.70
30	13.46	–	19.16	26.58	23.09	24.06	26.43	22.07	19.95	13.45	6.06	7.74
31	14.42	–	16.57	–	27.99	–	25.70	20.62	–	12.65	–	10.16

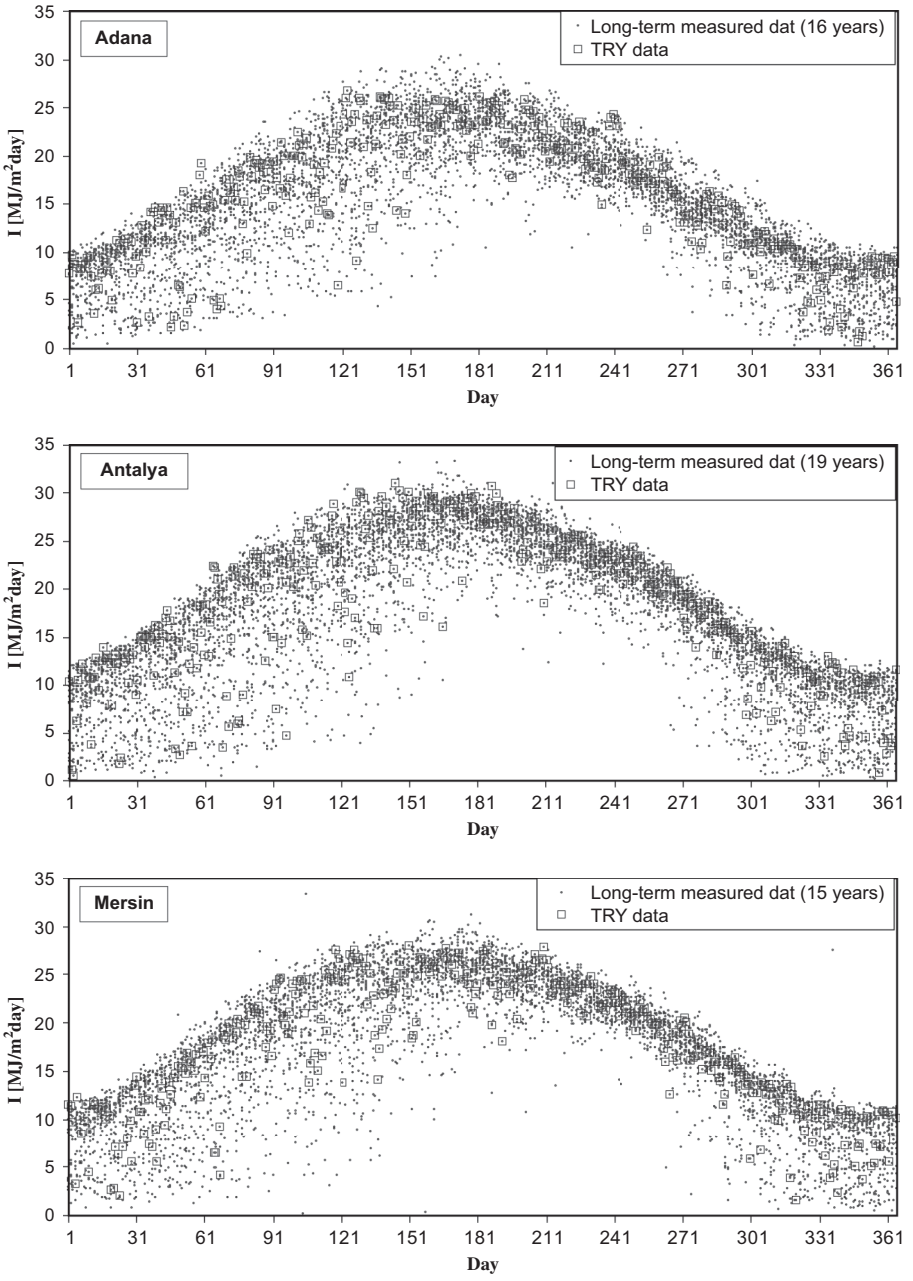

Figure 2 Variation of daily global solar radiation for Adana, Antalya, and Mersin.

GENERATION OF TYPICAL SOLAR RADIATION YEAR

By applying the above methodology for all the months in the database, the Test Reference Year for daily global solar radiation data was formed for six provinces of the Mediterranean region of Turkey. Due to a lack of wet-bulb temperature, relative

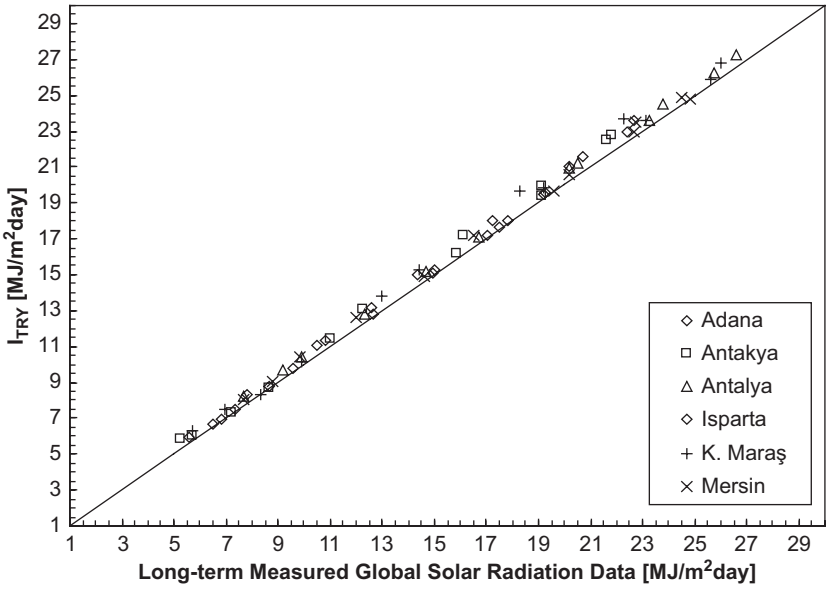

Figure 3 Comparison of monthly averages of the long-term measured global solar radiation data and TRY data for the provinces in the Mediterranean region.

humidity, and wind speed data, the study could not be extended to include these parameters.

The test reference years with minimum FS for monthly mean global solar radiation for six provinces considered in this study are given in Table 2. It can be seen from the table that, although the region is rich for solar energy potential, there are remarkable differences between the solar data of locations. The reasons for the differences are cloud formation and lower sunshine duration in some locations. As can be seen from Table 2, the minimum and maximum values of monthly mean of the daily global solar radiation on a horizontal surface (I_{TRY}) in the Mediterranean Region are, respectively, 5.88 MJ/m^2 in December in Antakya and 27.30 MJ/m^2 in June in Antalya. Annual average value of the daily global solar radiation in the region is 15.88 MJ/m^{2}day.

Although typical solar radiation years are formed for all the provinces considered, it is not practical to present all of them in this paper due to space limitations. Tables 3 through 5 show respectively examples for typical solar radiation year for Adana, Antalya, and Mersin, which are the biggest provinces in the Mediterranean region. Discontinuities between the adjacent months are evident, because the adjacent months are generally selected from different years.

Figure 2 shows the variation of the daily global solar radiation on a horizontal surface generated from test reference year and all the available long-term measured data for Adana, Antalya, and Mersin. It can be seen from the figure that both data fluctuate significantly and are very random throughout the year.

In Figure 3, typical solar radiation (I_{TRY}) data is compared with the long-term measured data set to see differences between I_{TRY} data and the measured data for all the locations considered in this study. Comparisons were made on a monthly basis for daily global solar radiation. As shown in Figure 3, there is a reasonably good agreement on a

monthly basis. It is seen that the I_{TRY} data is quite favorable on a monthly basis and always bigger than the long-term measured data.

CONCLUSION

Typical solar radiation data is very important for calculations concerning many solar applications and building energy analysis. In this study, test reference years for daily global solar radiation for six provinces located in the Mediterranean region of Turkey are produced using at least 14 years of the measured data. The daily global solar radiation on a horizontal surface for the region is presented throughout the year in a tabular form. It is seen that both long-term measured and the typical data are very random throughout the year. It is found that there is good agreement between the long-term data and typical data on a monthly basis. It is also seen from the data that the region has a high solar energy potential. It is expected that the presented typical solar radiation data for the Mediterranean region, which is rich for solar energy potential in Turkey, will be useful to the designers of solar energy systems.

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